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Superimposing Instrument Symbology on a Night Vision Goggle Display During Simulated Contour Flight

John C. Morey and Robert A. Simon
Dynamics Research Corporation

Dennis K. Leedom
U. S. Army Research Institute

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14. Abstract

This experiment examined the effect of superimposing helmet-mounted display (HMD) flight information symbology on the aviator night vision goggle (ANVIS). Twenty-five rated helicopter pilots with no previous HMD experience were assigned to either an ANVIS-HMD group or a goggles-only group (ANVIS-only). All pilots flew familiarization flights and an hour-long reconnaissance mission on the Simulator Training Research Advanced Testbed for Aviation (STRATA), a high fidelity simulator. HMD symbology and the night vision goggle effects were integrated into the out-the-window images. Performance of the ANVIS-HMD group was comparable to that of the ANVIS-only group with respect to maintaining airspeed and altitude, detecting targets, detecting wire obstacles, and landing in a confined area. Although ANVIS-HMD users' visual activity

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15. Subject Terms

night vision goggle	head-up display	eye dominance	helicopter
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14. Abstract (Continued)

was in the horizon area of the field of view 85% of the time (compared to 63% for the ANVIS-only group), they did not scan more effectively. No evidence of cognitive capture on the symbology was found. Pilot experience level and handedness were not associated with flight performance or target detections but eye dominance was.

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Superimposing Instrument Symbology on a Night Vision Goggle Display During Simulated Contour Flight

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Prepared by:

DYNAMICS RESEARCH CORPORATION
Systems Division
60 Concord Street
Wilmington, MA 01887

PM: Dr. Robert Simon

Prepared for:

USARIARDA/PERI-IR
Ft. Rucker, AL 36362

POC: Dr. Dennis K. Leedom

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SUPERIMPOSING INSTRUMENT SYMBOLOGY ON A NIGHT VISION GOGGLE DISPLAY DURING SIMULATED CONTOUR FLIGHT

EXECUTIVE SUMMARY

Research Requirement

This experiment investigated the performance and safety impacts of superimposing flight instrument symbology onto the aviator night vision imaging system (ANVIS) during a simulated reconnaissance mission.

Procedure

ANVIS-qualified aviators with no prior experience with a helmet-mounted display (HMD) were assigned to either an ANVIS-HMD group or a baseline group using the ANVIS alone (ANVIS-only group). All aviators completed daylight and night familiarization flights on the Simulator Training Research Advanced Testbed for Aviation (STRATA) prior to a one-hour reconnaissance mission. The reconnaissance mission required pilots to search for ground targets, avoid obstacles placed in the flight path, and land in a confined area. In addition to measures of flight performance, eye tracking data were collected to assess scanning patterns. These data also enabled assessments of fixations on instrument elements of the HMD. Pilot eye dominance and handedness was also assessed.

Findings

Aviators equipped with the ANVIS-HMD showed no advantage in maintaining airspeed and altitude, detecting targets, detecting wire obstacles, or controlling rates of closure into a confined area. Although the ANVIS-HMD users kept their eyes localized in the general area of the horizon 85% of the time compared to about 63% for the ANVIS-only pilots, their scanning patterns were no better than those of the ANVIS-only pilots. No evidence was found for cognitive capture on HMD symbology elements.

Pilot experience level was not associated with effectiveness in using the HMD display. Only one in five of the most successful pilots was an ANVIS-HMD user, whereas three of the five least successful aviators were ANVIS-HMD users. Eye dominance was associated with striking ground objects and target false detections. Handedness was not associated with any cognitive performance differences. All pilots in the ANVIS-HMD group appeared to adapt to the superimposition of flight information on the field of view with a minimum of familiarization.

Utilization of Findings

The results demonstrate that rotary wing pilots can readily adapt to essential flight information superimposed on the ANVIS out-the-window (OTW) scene. Flight safety does not appear to be compromised with the ANVIS-HMD configuration, but improved scanning and detection is not an inherent consequence of remaining "head up". Other performance impacts and training requirements for the ANVIS-HMD system need to be examined in greater detail.

SUPERIMPOSING INSTRUMENT SYMBOLOGY ON A NIGHT VISION GOGGLE DISPLAY DURING SIMULATED CONTOUR FLIGHT

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Advanced electro-optical systems enable military helicopter pilots to fly with increased effectiveness at night not possible twenty years ago. One example of these systems is the night vision goggle (NVG), which intensifies low level visible and near-infrared light. Despite more than two decades of operational use, the impact of NVGs on pilotage is still not well understood (Kaiser & Foyle, 1991). Some perceptual problems associated with the current fielded versions of the aviation NVG, the AN/PVS-5 and the Aviator Night Vision Imaging System (ANVIS), are erroneous assessment of aircraft drift, distance misjudgments (e.g., altitude, obstacle clearance), disorientation, and degraded visual discriminations due to poor resolution and reduced contrast. These and other NVG-related problems are reviewed by Ruffner, Grubb, and Hamilton (1992). In spite of these drawbacks, night flight operational effectiveness and safety have improved through technological advances to the NVG, aided by improved crew coordination procedures and training associated with their use.

An additional technology improvement being planned is the integration of flight instrument symbology into the visual array of the ANVIS. This development is an application of the head-up display (HUD) concept that permits the pilot to observe flight information superimposed on the out-the-window (OTW) scene viewed through the ANVIS. The specific display configuration being implemented is referred to as a helmet-mounted display (HMD). An HMD is fastened to the flight helmet in contrast to the HUD, which projects the symbology onto a surface at or near the windscreen. The integrated ANVIS-HMD introduces the flight symbology into one of the pair of ANVIS intensifier tubes that are attached to the pilot's helmet[1].

The ANVIS-HMD is designed to eliminate the pilot's need for in-the-cockpit viewing of critical flight information. Currently, pilots must divert their eyes downward from the ANVIS to read cockpit instruments. This eye movement entails changes in optical distance and illumination levels that may be associated with visual accommodation and perceptual difficulties (Ruffner, et al. 1992). Pilots can avoid these difficulites by having the copilot read the instruments and provide verbal reports of aircraft status. This, however, requires well-developed crew coordination procedures and creates the potential for increased crew workload. By presenting flight information simultaneously with the OTW

[1] Army literature refers to this configuration as an ANVIS-HUD, but the term ANVIS-HMD is used in this report for technical accuracy.

image, the ANVIS-HMD is expected to eliminate some of the vision and crew coordination impacts of using the ANVIS.

However, the combination of the ANVIS and HMD technologies may pose some performance problems. Brickner and Foyle (1990) investigated whether the restricted field of view typical of NVGs affects maneuver performance. They presented subjects a helicopter flight simulation task that required flying through a slalom course of pylons spaced an average of 600 feet apart. Horizontal field of view of the scene varied between 25, 40, and 55 degrees. The subjects also monitored a HUD overlaid on the scene to maintain altitude while maneuvering between the pylons. As the field of view became more narrow, subjects flew closer to the pylons, registered more pylon strikes, and missed more slalom gates. With respect to the OTW scene's quality, the absence of ground texture in the visual scene impaired pilots' performance, as compared with a scene that provided a grid to represent the ground. Taken together, the results of this experiment suggest that the restricted field of view of the ANVIS-HMD results in difficulties in maneuvering a helicopter. This effect is exacerbated by the reduced quality of visual details characteristic of NVG images.

Brickner and Foyle (1990) did not measure performance related to information provided in the HUD; that is, they did not measure how well subjects maintained the designated altitude. The possible trade-off between the HUD and OTW tasks was investigated by Foyle, Sanford, and McCann (1991). Subjects flew a simulated slalom course under conditions that included (a) HUD altitude readings present or absent and (b) buildings present or absent. A grid pattern represented the ground; small pyramidal pylons denoted the flight paths. The tasks were to (a) fly through the gaps in the pylons, (b) avoid pylon hits, and (c) maintain the designated altitude.

The buildings-present condition in Foyle et al.'s (1991) study provided altitude references integral with the external world. In contrast, the HUD provided altitude information in the form of an object perceptually separate from the external world view. Performance differences were predicted to depend on whether parallel processing of the OTW scene and altitude information would be better for the external (building-referenced) or the internal (HUD-referenced) altitude source.

Compared with a no altitude information condition, the HUD condition resulted in better maintenance of altitude but at the cost of larger deviations from the prescribed flight path, thus supporting a similar finding by Brickner (1989). However, the buildings-present condition also resulted in better altitude maintenance but without concomitant increases in flight path errors. Foyle et al. (1991) suggested that the perceptually segregated HUD impaired parallel processing of altitude information and external scene cues necessary for maneuvering.

Brickner (1989) and Foyle et al. (1991) assessed HUD performance with respect to clearly visible, predictable OTW cues (pylons or buildings) used to time and execute flight control (motor) actions. Fisher et al. (1980) investigated what effect using a HUD has on pilots' attention to unexpected events. In their experiment, experienced 727 pilots flew a variety of HUD and non-HUD landing approaches in a simulator under restricted ceiling and visibility conditions. The HUD presented conformal flight path symbology that provided sufficient information so that a pilot could land without directly using the visual runway. During two landings, a wide-body aircraft was placed midway onto the runway, as if turning from the adjoining taxiway. Two of four pilots using the HUD on their first exposure to the obstruction on the runway failed to see it; the four pilots in the non-HUD condition saw the obstruction. On their second exposure to the obstruction, all pilots saw the obstruction whether using the HUD or not.

The failures of experienced pilots to see the obstruction on its initial exposure raised a safety concern regarding HUDs. However, Fisher et al. (1980) examined this finding in some detail, and cautioned that the informational richness of the particular HUD used, the conditions of its use, and the novelty of the HUD as an aid to approach and landing (despite training and practice) had much to do with this result. In particular, the HUD provided more accurate and complete information than could be garnered from the OTW scene. Thus, perhaps too much useful information was presented, which diminished the pilots' need to divide attention between the HUD and the OTW scene. Also, the abundance of symbols prompted some pilots to suggest decluttering the HUD display, especially in the center portion.

Fisher et al. (1980) also pointed to the simulation environment as a factor contributing to the failures to detect the runway obstrucion. The qualities of three-dimensional depth and image resolution in their simulation were poorer than real-world images. This may have contributed to exaggerated tracking of the more distinct symbology. In addition, pilots in this experiment were not told of possible obstructions. In the real world, the possibility of obstructions and other unexpected events is an ever-present concern. The effect of heightened awareness of unexpected events is borne out in the pilots' second encounter with the obstruction: all perceived it.

Weintraub, Haines, and Randle (1984, 1985) investigated the effects of varying optical distances to head-up and head-down displays while monitoring the OTW scene for runway markers. Images were presented as static slides of symbology displays and runways. The symbology was presented as a HUD image or a head-down display image at a 10° downward gaze angle. For both symbology presentation modes, optical distance was varied between 0 diopters (optical infinity), 1.33 diopters (727 instrument panel distance), 2.67 diopters (map-reading distance), and 4 diopters (wristwatch reading distance). In one experiment, subjects first determined if altitude and airspeed exceeded tolerance values and then inspected a runway scene to detect a land-no land symbol appearing on the runway. In the second experiment, the runway decision preceded the altitude and airspeed determinations.

The critical comparison in Weintraub et al.'s experiments (1984, 1985) was between the HUD presented at 0 diopters and the head-down display presented at 1.33 diopters. This corresponds to a comparison of the HUD presented at optical infinity with viewing the same information on an instrument panel. Out-of-tolerance airspeed and altitude were reported 80-90 msec faster with the HUD in both experiments. However, a cost was associated with runway decision times. Decision times were slowest with the HUD at 0 diopters but increased as optical separation between the HUD and the OTW scene became greater (i.e., increased from 0 to 4 diopters). Therefore, placing the HUD in the same optical plane as the external scene to produce a more uniform or "fused" image resulted in a performance decrement associated with pilots switching their attention between the HUD and OTW scene.

On the other hand, runway decision time was not affected in a comparison of the HUD with the head-down display, each considered at a viewing distance of 0 diopters (notwithstanding that a head-down display at optical infinity is artificial with respect to the real world). Weintraub et al. (1984, 1985) interpreted this to mean that no decision time was lost in the act of looking down.

Drawing on the results of prior HUD experiments, Larish and Wickens (1991) integrated a number of key factors in their "comprehensive evaluation of attentional phenomena with both head up and head down presentation when optical distance differences and symbology were identical for the two formats" (p. 13). They examined the following issues in their experiment:

1. Comparison of head-up and head-down display mode

2. Comparison of the pilot's ability to detect expected and unexpected events both in the display and the OTW scene

3. Comparison of high and low workload conditions on the pilot's flying performance and event detection

4. The effect of cuing the user to scan the external scene to detect events.

Larish and Wickens' (1991) testing took place on a workstation that presented the OTW scene. The same workstation also presented the symbology for the HUD condition. An additional monitor placed below the workstation provided the display for the head-down condition. An experimental trial consisted of a dynamic simulation of an instrument landing system (ILS) approach to landing lasting about 6 minutes. The scenario consisted of a series of five breakouts from clouds at various altitudes. A trial began with the aircraft in the clouds at 2000 feet. The first breakout from the clouds occurred at 1260 feet. During descent, the pilots had to continue flying by instruments even though they had visual contact with the runway. With each breakout, the pilot had to determine if a symbol at the side of the runway was red or yellow, and register a response with a button press on a joystick used to maneuver the simulated aircraft. This response was a means of measuring the time required to switch attention from the symbology to an expected (cued) external event. In addition, at three unspecified times, a master warning (either a 0 or 1) appeared in the symbology. Pilots had been told to expect such a warning, to which they had to press a corresponding 0 or 1 key. Their response was a means of measuring the time required to switch attention from the external scene to a symbology event. Pilots were also required to maintain airspeed at 90 knots. For each trial, high or low workload was created by varying the level of turbulence.

Thus, the subjects, all rated pilots, responded to two kinds of expected events: the presence of a runway symbol and the appearance of the master warning on the display. Unexpected events consisted of an aircraft taxiing onto the runway near the touchdown point, and the appearance of a wind shear warning on the display. Pilots were instructed to press a response button and initiate an abort procedure if a wind shear or any other condition precluded a safe landing. However, they were not warned of possible runway obstructions.

Larish and Wickens' (1991) comparison of the HUD to the head-down display revealed no flight performance differences as measured by root mean square (RMS) localizer deviation, RMS glideslope deviation, course deviation, heading deviation, speed, and a set of instantaneous measures occurring at touchdown. Reaction time to one of the expected events, the runway symbol, did not differ between the two display modes. However, high workload increased reaction times for the master warning in the head-down display but not in the HUD display. Regardless of workload level, the HUD resulted in faster reaction time to the master warning when compared to the head-down display.

Workload in Larish and Wickens' (1991) experiment also affected the reaction times to unexpected events in the form of a significant interaction between display mode and workload. Under high workload, the HUD resulted in a delay of about 8 sec as compared to head-down display for detecting the wind-shear warning. Low workload resulted in essentially equivalent reaction time between the HUD and head-down display. With respect to the runway obstacle, the interaction was similar but did not reach statistical significance ($p < .107$). Under high workload, mean response time for the HUD was 5.25 sec slower than that for the head-down display. Low workload resulted in equivalent reaction times. However, a Wilcoxon test (used because of the large differences in HUD and head-down response time variances) revealed that overall HUD response time was significantly slower than head-down response time.

These results lead Larish and Wickens to the following four conclusions:

1. The HUD pilots showed no performance advantage in controlling the aircraft.

2. The HUD did not impede the pilots' detecting and reporting an expected OTW event, the runway symbol heralded by the distinctive cue of breaking out of the clouds.

3. The HUD showed a distinct advantage with respect to the other expected event--the master warning--known to appear in the symbology display but at unpredictable times. Not only was the pilots' master warning signal reaction time fastest for the HUD, but their reaction time was not affected by high workload.

4. The HUD revealed a significant disadvantage in pilots' reaction time to both of the unexpected events--wind shear warning and runway obstacle--under high workload.

The Larish and Wickens' (1991) study is noteworthy in combining significant independent variables from earlier HUD studies with a moderate level of operational realism. However, the visual presentation in their experiment was a daylight condition under visual flight rules. The desirability of investigating HUD performance using realistic ANVIS viewing conditions prompted McAnulty, Ruffner, and Hamilton (1992) to videotape scenes through a nose-mounted camera in a helicopter. Because they were interested in assessing the performance effects of adding instrument symbology to the ANVIS, they developed a special apparatus to present the videotaped scenes, HMD instrument symbology, and NVG visual effects. The apparatus permitted the symbology to be presented to the right eye only, which is the arrangement planned for the UH-60 ANVIS-HMD configuration. Scenes and symbology were presented to rated helicopter pilots.

McAnulty et al. (1992) presented aviators with videotape vignettes of low level flight and traffic patterns through two monitors. Each eye viewed the same vignette through a separate video monitor, but the monitors were positioned so that the pilot perceived a single fused image. This arrangement permitted a computer-generated set of instrument symbology to be superimposed on the image presented to the right eye. To simulate the reduced field of view of the ANVIS, black circular masks were placed in the line of sight to reduce the image to a 40° circular field of view. Lens placed the apparent viewing distance of the displays at 1.9 m, equivalent to the average viewing distance to which aviators adjust their ANVIS goggles. In addition, chromatic filters adjusted the display color to the characteristic green of the ANVIS. Although all the dynamic elements of the symbology suite changed values during the course of a trial, only four were monitored for out of tolerance values: airspeed, altitude, trim, and master caution warning.

The pilots viewed a scene-only segment, a symbology-only segment, and a segment with symbology superimposed on the scene. Each test segment was preceded by practice trials. The symbology-only segment contained the symbology suite presented against a blank background. The symbology was monitored for out-of-tolerance values that were signalled with right-hand keypresses on a numeric keypad. The scene-only segment was monitored for appearances of designated terrain features and changes in position of another helicopter flying in formation. Detections were signalled with a left-hand button press and verbal report. The combined symbology and scene segment presented the same types of visual images (with symbology superimposed on the scene) and required the same monitoring tasks and responses.

McAnulty et al. (1992) found that aviators detected a high percentage (above 80%) of the symbology-only out-of-tolerance states with a reaction time of less than 2 sec per element. On the other hand, aviators detected between 60 to 69% of scene-only features and events at an average reaction time of nearly 4 sec. With the symbology superimposed on the scene, detection of either symbology or scene events was approximately 69% with a small, but not statistically significant, increase in reaction time. These data show that the pilots detected HMD information, when presented by itself, more successfully than OTW information. A significant finding was that performance was degraded when both sources of information were superimposed. Moreover, the degradation was equivalent for both types of information when presented together. One source of information did not "capture" attention to the detriment of the other. A small improvement in scene and symbology event detections was noted when detection rates of later trials were compared with those of earlier trials.

Individual differences in experience and sighting dominance played a significant role in performance. Less experienced pilots detected more of the symbology events, and with faster reaction times, than more experienced pilots. On the other hand, the experienced pilots reacted faster to the scene targets than did the less experienced pilots.

Sighting dominance also had an effect on detection of key events in McAnulty et al.'s (1992) experiment. Sighting dominance is the habitual favoring of one eye in monocular sighting tasks, such as looking into a microscope, or the use of one eye when the binocular images are discrepant or infusible (see Porac & Coren, 1976, for a discussion of the various forms of eye dominance). Right-eye dominant pilots detected more scene and HMD events when the HMD and scene were viewed together; however, right-eye dominant pilots' reaction time to scene targets was slower when viewed in conjunction with the HMD than when they viewed scene events alone. Eye dominance showed no effect in the number of detections when scenes or symbology were viewed alone.

Only a few studies have investigated the differential effects of presenting information to one eye (dichoptic viewing) or both eyes (binocular viewing). In a study of attention to two unrelated video images, Neisser and Becklen (1975) superimposed two videotapes, each depicting different kinds of events. They compared performance under both binocular and dichoptic viewing conditions. In the binocular condition, the videos were superimposed on one viewing screen. In the dichoptic condition, subjects viewed one video with the left eye and a second video with the right eye. Superimposed video images, regardless of binocular or dichoptic viewing, resulted in poorer detection of target events as compared to single video presentation. However, the binocular viewing condition resulted in subjects better detecting target events than did the dichoptic condition.

Gopher, Grunwald, Straucher, and Kimchi (1990) compared dichoptic and binocular viewing in subjects who flew a low fidelity simulated helicopter. Keeping the helicopter on course required aligning a cross within a square. The cross and square were presented (a) binocularly, (b) together in one eye, or (c) separately to each eye. A secondary letter detection task was presented either to the eye receiving the tracking symbols or to the other eye. Overall, response time to the letter classification task increased under the dichoptic viewing conditions. However, subjects' response time under dichoptic conditions did not differ when (a) the letters were presented to the same or different eye from the tracking symbols or (b) when the tracking symbols were presented together to one eye or separately to each eye. Moreover, the best reaction time to letter pairs occurred when the pair appeared superimposed on the tracking symbols.

Gopher et al.'s (1990) results demonstrate that a secondary task presented to only one eye causes some degradation of performance. However, information processing capacity for the two tasks (tracking and classification) is not further degraded when both tasks are presented to one eye.

Kimchi, Rubin, Gopher, and Raij (1989) investigated subjects' ability to focus and divide attention under conditions of binocular and dichoptic viewing. Their subjects engaged in search tasks that required them to search for a target among two objects, search for a target among two elements that composed the objects, or search at both levels simultaneously.

In the dichoptic viewing condition, one stimulus was presented to the subject's left eye and the other to the right. In the binocular viewing condition, both eyes viewed the stimulus pair. The search task involving the stimuli was performed under two attention conditions. In the focused attention condition, the subject was instructed to attend to only one stimulus: the stimulus appearing in either the left or right eye under the dichoptic viewing condition; the stimulus appearing in either the left or right visual field under the binocular viewing condition. In the divided attention condition, the subject was required to attend with both eyes or to both visual fields.

The overall result of Kimchi et al.'s (1989) experiment was that subjects' ability to focus and divide attention under dichoptic viewing was not significantly different than their ability to do so under binocular viewing. In addition, if the subject had to focus on one stimulus, that focusing "set" facilitated selecting one aspect of the selected stimulus for further processing. Furthermore, a similar "set" operated at the global level. Thus, it was concluded that an observer attended better to global details of an object if he or she was dividing attention between objects.

With respect to dichoptic viewing, the Neisser and Becklen (1975) and Gopher et al.'s (1990) studies show that when subjects dichoptically viewed dynamically changing images, their performance degraded a small but demonstrable amount. However, selective and divided attention effects appear to operate similarly when either one or two eyes are engaged in performing a task as demonstrated in the Kimchi et al. (1989) study. Significantly, however, none of the studies that presented stimuli to one eye determined whether the stimuli were being presented to the subject's dominant or nondominant eye.

The McAnulty et al. (1992) experiment specifically examined the eye dominance issue and extended dichoptic viewing research to the HMD situation by assessing aviation tasks performed by rated pilots. However, the pilots in their experiment were passive observers of events in that they exercised no control of the simulated aircraft. The pilots in the experiment may have adopted attentional strategies that involved monitoring instrument readings and searching the outside visual scene in a manner that was substantially different from those used when actually flying an aircraft.

Therefore, the major issue underlying our experiment was an examination of the beneficial and hazardous consequences of the ANVIS-HMD configuration when the pilot is in control of the aircraft. Among the experimental conditions we enlisted to reveal these consequences was requiring pilots to fly an hour-long mission under a demanding contour flight regime. Contour flight is low altitude flight that conforms to the contours of the earth and requires constant attention to, and corrections for, airspeed and terrain clearance. Other conditions required the pilots to (a) continuously search the OTW scene for ground targets and (b) search for and avoid hazards such as trees and wires deliberately placed in the flight path. Although pilots were warned to expect wires in their flight path, the specific locations of the wire hazards were not specified.

Imposing these conditions on pilots required using a high fidelity flight simulator, the Simulator Training Research Advanced Testbed for Aviation (STRATA), that was especially suited to creating the visual and scenario conditions for the experiment. A description of STRATA is provided in the Method section. The next section describes our experimental design and research hypotheses.

Experimental Design and Research Hypotheses

The purpose of the present experiment was to compare the performance of pilots using HMD symbology superimposed on an ANVIS display of the OTW scene with the performance of pilots using conventional cockpit instruments and viewing an ANVIS display of the OTW scene. These are referred to as the ANVIS-HMD condition and ANVIS-only condition, respectively. The experimental conditions were arranged as a three-factor mixed factorial design, with between subject factors of experimental condition (ANVIS-HMD and ANVIS-only) and experience level (high and low), and a within subjects factor to represent multiple occurrences of targets, master caution warnings, and obstacles. The primary measure of performance was how well pilots stayed within designated altitude and airspeed envelopes. Other measures included the number of ground targets detected, the number of collisions with power transmission wires and other obstacles, reaction times to master caution warning indicator onset, and rates of closure into a confined area.

Hypotheses for this experiment were developed to be consistent with the results of earlier HUD research. However, predicted improvements in performance with the HMD were based on the fact that helicopter pilots have to remain head-up during contour flight and target search. These "head-up" requirements should prove to be beneficial to the ANVIS-HMD users. The five hypotheses for this experiment were as follows:

1. Pilots using the ANVIS-HMD will show less variability in maintaining airspeed and altitude than will pilots in the ANVIS-only condition.

2. Pilots using the ANVIS-HMD will detect more ground targets than will pilots in the ANVIS-only condition.

3. Pilots using the ANVIS-HMD will react faster to master caution warnings than will pilots in the ANVIS-only condition.

4. Pilots using the ANVIS-HMD will demonstrate fewer collisions with wires than will pilots in the ANVIS-only condition.

5. No differences in rates of closure into a confined area will be shown in comparisons between the ANVIS-HMD and ANVIS-only conditions.

In addition to these hypotheses, exploratory analyses were planned to examine eye dominance and brain laterality effects. Eye dominance (specifically, sighting dominance) was revealed in McAnulty et al.'s (1992) experiment to be a moderator of performance for ANVIS-HMD users. Brain laterality effects appeared as a possible source of performance differences based on a recent review of cognitive and attention factors associated with HUD use (Morey & Simon, 1991a). Brain laterality refers to findings that in right-handed individuals, the left side of the brain processes verbal information more effectively, and the right side of the brain processes nonverbal, spatial, and perceptual information more effectively. These differences may not apply in left-handed individuals (Beaton, 1985; Bryden, 1982).

Handedness is a conveniently obtained indicator of the differentiation of information processing functions of the cerebral hemispheres (Beaton, 1985). Assessment of handedness was carried out in our experiment using a specially designed questionnaire (Morey & Simon, 1991b).

Method

Subjects

Twenty-eight aviators from units and organizations at the U.S. Army Aviation Center, Fort Rucker, Alabama, were recruited as subjects. Requests for aviators specified that the participants were to be NVG qualified. However, aviators were to have had no operational experience with HUDs, a requirement that excluded pilots whose primary aircraft was the AH-64 Apache helicopter. One pilot reported that he had participated in a recent experiment that investigated the effects of HUD use in conjunction with a search task. Because that experiment used the pilot as a passive observer for viewing time lasting approximately 45 min, the pilot's limited HUD experience was judged not to preclude his participation in the current experiment.

Organizations were selected for subject recruitment to obtain rated pilots with high and low number of flight hours and different primary aircraft experience. The initial sample of subjects included 13 recent Initial Entry Rotary Wing (IERW) graduates with one year or less as a rated aviator (i.e., inexperienced pilots) and 15 pilots and instructor pilots from support units at Fort Rucker (i.e., experienced pilots). Two of the experienced pilots served during the first two days of experimentation to pretest experimental procedures and simulator operations. While monitoring the performance of a third experienced pilot, experimenters judged his performance in controlling the simulated aircraft's airspeed, altitude, and trim as substandard. Data from that subject, together with data from the initial two subjects, were eliminated from subsequent analyses.

The final subject pool consisted of 13 inexperienced pilots and 12 experienced pilots. Their biographical and aviation experience data are shown in Table 1. Table 2 shows eye dominance and handedness data obtained using methods described by Morey and Simon (1991a). The handedness data was skewed distinctly towards right-handedness, with only two pilots reporting left-hand preference. Subjects were randomly assigned to the ANVIS-only or ANVIS-HMD condition so that as nearly as possible, equal numbers of experienced and inexperienced pilots served in each experimental condition.

Equipment

STRATA is a simulator specially designed for research and development purposes. The image generation and display capabilities, scenario development environment, and data recording facilities each provided the flexibility to configure the simulator to the particular demands of the ANVIS-HMD experiment. The most relevant features are described in the following paragraphs[2].

Hardware characteristics. STRATA is configured as an Apache AH-64 attack helicopter with separate pilot and copilot stations (cockpits). The stations are made from actual aircraft crew stations. Cockpit components are controlled through software simulations of aircraft systems and aerodynamic models of the AH-64 so that the functional characteristics of instruments and flight controls are closely tuned to those of the actual aircraft. Because the stations are on a motionless platform, sensations of acceleration are provided by inflatable bladders in the seats (i.e., g-seats). With the exception of motion, the look and feel of the STRATA crew station seats and instrument panels are the same as those in the actual aircraft. The cockpit canopy has been removed, but wind screen support members and the rotor are part of the visual scene presented to the aviator.

Image generation and display systems. Visual scenes on STRATA are created by an Evans and Sutherland ESIG-1000 image generation system. Color displays are presented to the pilot using the Fiber Optic Helmet Mounted Display (FOHMD), which is illustrated in Figure 1. Separate images are created for the left and right eye and presented to the eyes on individual eyepieces. The eyepieces are somewhat transparent, which permits the pilot to look down and through the visual system to view the instrument panel. Because the copilot station was not used in this experiment, an

[2] Detailed descriptions of STRATA may be obtained from the U.S. Army Aviation Research and Development Activity, ATTN: PERI-IR, Fort Rucker, Alabama 36362-5354.

Table 1

Biographical and Aviation Experience Data

Variable	Experienced			Inexperienced		
	n	*M*	*SD*	*n*	*M*	*SD*
Age (Years)	12	32.9	6.5	13	24.2	1.4
Sex						
Male	12			10		
Female	-			3		
Rank						
2^{nd} LT	1			13		
CPT	1					
CW2	5					
CW3	3					
DAC[a]	2					
Years as rated aviator	12	7.7	7.0	13	0.1	0.08
Duty position						
SP	2					
IP	1					
UT	3					
Aviator	6			13		
Primary aircraft						
UH-1	8			4		
UH-60				7		
OH-58	3			2		
CH-47D	1					
Primary aircraft hours (Lifetime)	12	2254.8	1765.9	12	112.8	46.5
Primary aircraft hours - NVG	12	342.1	468.3	13	16.7	4.7
Primary aircraft hours (Last 6 months)	9	198.9	66.5	12	87.0	32.2
Primary aircraft hours - NVG (Last 6 months)	4	137.5	85.4	13	16.9	4.7

[a]Department of the Army civilian instructor pilot

Table 2

Sighting Dominance and Handedness Data

Measure	Experimental group	
	ANVIS-HMD	ANVIS-only
Sighting dominance	Left = 30.7% Right = 69.2%	Left = 36.4% Right = 63.6%
Handedness	Left = 7.7% Right = 92.3%	Left = 8.3% Right = 91.7%

alternative display system at the copilot's station is not described.

Images are created with a larger, low resolution background channel and a smaller, high resolution inset channel. The inset channel provides higher resolution imagery for the central region of the eye. In normal operations, the field of view for the background channel is 127° by 66° and for the inset channel 25° by 19°. As described in greater detail later, to simulate the ANVIS-HMD a reduced field of view was created for this experiment by using the background channel exclusively; the inset channel was not necessary in this mode because of the reduced resolution of the ANVIS image. Collocated with the eyepieces are eye tracker sensors that are used to position the inset channel and record eye movement data.

As shown in Figure 1, the imagery is transmitted to the helmet by fiber optic cables. The helmet also contains a light emitting diode (LED) array on top of the helmet. Signals from the top of the helmet are sensed by infrared cameras to create head position information. This information is used in conjunction with rate sensor and simulator position data to select the visual scene corresponding to the direction of the pilot's gaze. Although the pilot could direct his or her view to any location, seating and movement constraints created by the fiber optic cables restrict left-right movements to approximately ±90° from forward.

Scenario development capabilities. STRATA contains a software application called Interactive Tactical Environment Management System (ITEMS). ITEMS consists in part of an off-line database management system that enables the researcher to define vehicles, aircraft, and fixed sites (collectively called players) for the tactical scenario in which the AH-64 (referred to as the ownship) operates. ITEMS permits the researcher to define the positions and actions of air and ground players within the terrain database chosen for the scenario. The appearance and

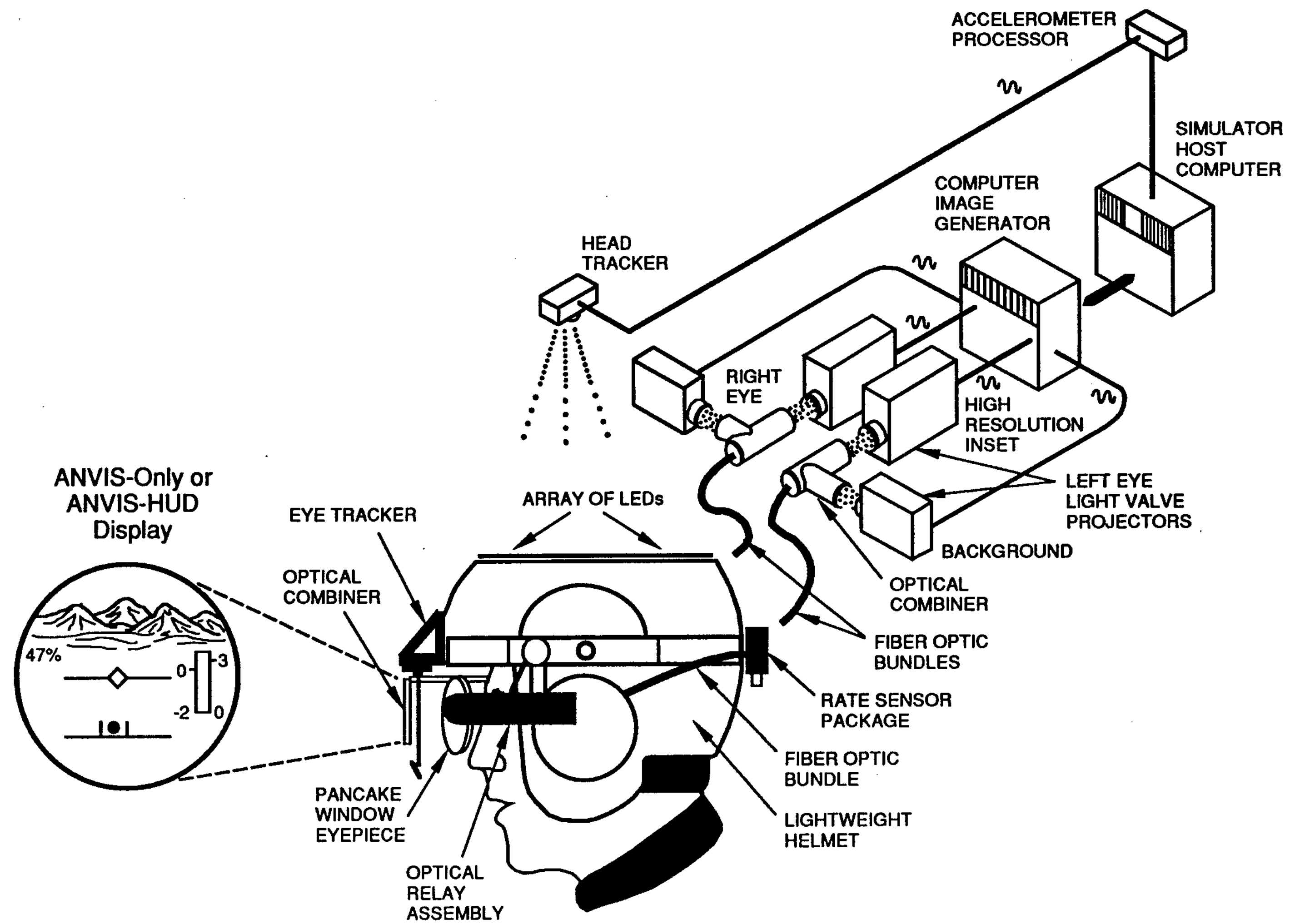

Figure 1. Illustration of components of the Fiber Optic Helmet Mounted Display (FOHMD).

tactical behaviors of up to 44 players may be defined. However, this experiment required the creation of power transmission towers and wires, and a Forward Arming and Refueling Point (FARP) consisting of carefully arranged trees and other features. To meet this requirement, programmers built these objects within the terrain database as features of the environment. Likewise, vehicles positioned as fixed target sites were built as terrain features, which alternatively could have been accomplished using ITEMS database. ITEMS was used to create the logic that turned on the master caution warning at distances of 2 to 28.5 km from designated waypoints and recorded reaction time to the occurrence of a trigger pull or a 20 sec timeout, whichever came first.

Data recording. Data collection is accomplished by the Data Recording and Analysis System (DRAS). The researcher defines the data recording requirements on a background utility that creates modules that subsequently run in the foreground during an experimental session. Central to data recording is the specification of events based on conditions that occur during the simulation. An example of a condition that might define an event is crossing a waypoint. When a condition becomes true, data is automatically recorded for any measurements specified for that event. Measurements can be values such as simulation parameters, ownship and player system states, time and position data, or values computed from a number of individual measures. Performance measures used in this experiment are described in the next section.

Experimenter-operator station. The Experimenter-Operator Station (EOS) provides the capability to load, activate, freeze, and terminate a scenario. Certain capabilities of the ownship can be monitored and changed (e.g., fuel level), whereas other system states (e.g., ownship instrument settings) can be viewed on graphical displays but cannot be changed. Environmental conditions, such as clouds or turbulence, can also be activated.

Monitoring and control of the experiment is accomplished with three kinds of displays. A bird's eye view tactical situation display map provides a contour map of the terrain database and icons of the ownship and other players. Positions of moving objects are continuously updated. A forward view display assumes an eyepoint corresponding to the ownship center of gravity, or an eyepoint offset to any position relative to the ownship. This provides a vantage point to anticipate upcoming events or view an event from a narrower or broader perspective. The third type of display is views of the background and inset channels to see (through monitors called repeaters) what the pilot is seeing.

Materials

Scenarios. Two exercise scenarios were designed and implemented on STRATA for this experiment. Each of the scenarios consisted of a predetermined flight path in which the pilot would encounter stationary ground targets and flight obstacles (e.g., wires and trees) and would experience master caution warnings triggered in proximity to designated waypoints. The first scenario was developed for familiarization with the tasks of target search, navigation, and maintenance of airspeed and altitude. The second scenario was a reconnaissance mission flown for performance assessment. Both scenarios were sited in the STRATA high resolution region of the Arizona terrain database. The general area of operations for both scenarios was the area to the north and east of Phoenix.

The first scenario (familiarization) began at Falcon Field on the northern edge of Mesa, Arizona. The flight path initially traversed an area of flat terrain from Falcon Field to the northern edge of the Superstition Mountains, which marked the transition to hilly and semi-mountainous terrain. The flight path then turned northerly and followed First Water Creek to Canyon Lake. The flight path followed the shoreline of Canyon Lake to the northeast until the lake narrowed into a creek. At this point, the flight path turned south, intersected with Interstate Route 87 and followed the highway west to where it intersected with First Water Creek. The final leg of the familiarization scenario retraced First Water Creek south and then the corridor east toward Falcon Field.

During the course of this scenario, the master warning indicator was triggered to illuminate in proximity to three waypoints. In addition, three target locations were established along First Water Creek. At each location, visual models of single or multiple vehicles (tracked or wheeled) were added to the database. Warnings and targets are explained in greater detail in the next section.

The second scenario (reconnaissance mission) consisted of the flight path shown in Figure 2. The flight path began at Falcon Field and proceeded northeasterly to the intersection of the Verde River and the Southern Canal (the start point (SP)). The flight path then followed the Verde River north along gently rolling terrain to Bartlett Dam. The course traversed the eastern shore of Bartlett Reservoir and again rejoined the Verde River proceeding northwesterly through increasingly hilly terrain to Horseshoe Dam. The flight path then turned west to briefly follow a viaduct before turning northwestly to ascend through a draw to the summit of Humboldt Mountain.

The first segment of the scenario provided seven target sites and two master caution warning signal onsets. Locations of the target sites and master caution events are shown in Figure 2.

The second segment of the scenario began with the descent from Humboldt Mountain along a road that subsequently connected with a secondary road proceeding southerly along Seven Springs Wash. This road then connected with another secondary road that

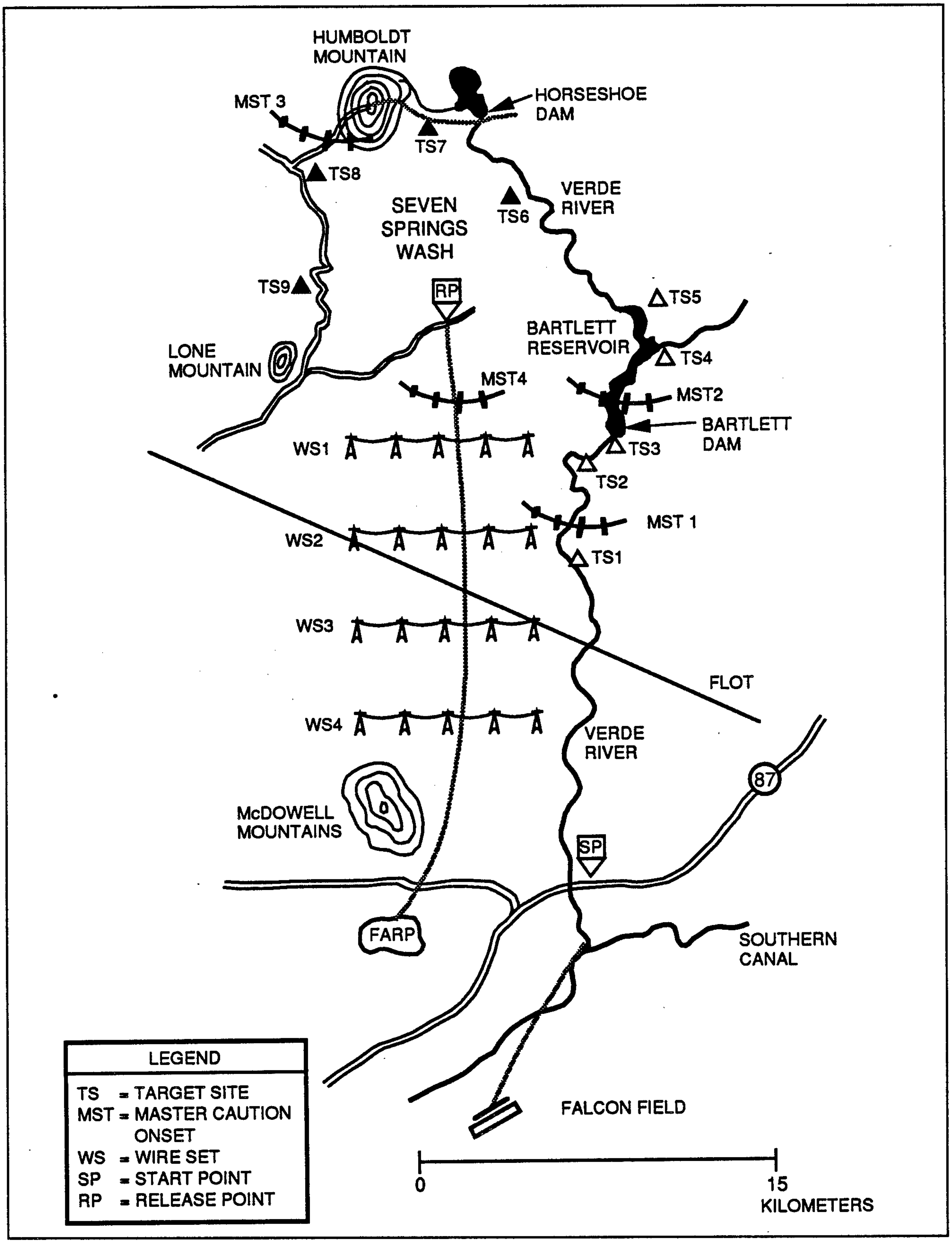

Figure 2. Reconnaissance scenario map.

turned the flight path southwesterly towards Lone Mountain. At the intersection of the secondary road and a state highway, the route turned east along the state highway towards the release point (RP). At the release point, the flight path continued on a southerly heading passing to the east of the McDowell Mountains and terminated at the FARP, located approximately 27 kilometers from the release point.

The second segment included two target sites and two master caution signal onsets. On the final leg of the scenario, four sets of power poles and wires were positioned at right angles to the flight path. These wire sets were not posted on the pilot's briefing map. The second segment terminated at the FARP that consisted of three refueling points in a clearing of a forested area. Inverted "Y"s defined approach paths to the northeast and northwest through breaks in the tree line. Either approach path required descending over tree tops through relatively narrow passages in the tree line.

Locations of the targets, wire obstacles, master caution events, and the FARP are shown in Figure 2. Characteristics of the nine targets and four wire sets are summarized in Table 3.

NVG and HMD visual effects. The NVG effect of narrowing the field-of-view was created in the image generation process by using a utility program to produce a black mask that was integrated into the left and right background channels. The mask replaced peripheral images so that when the left and right channels were correctly aligned to create a fused image, the 40° circular field of view was obtained. To the observer, the visual effect was a circular image surrounded by black.

The OTW images within the 40° circular field of view were rendered in monochromatic green by creating a special color file in the image generator. In order to create the contrast and hue effects of the black-hot polarity characteristic of the AN/AVS-6, four NVG-experienced aviators and researchers provided judgements of contrast and hue during individual color tuning sessions. The observer sat in the cockpit wearing the FOHMD helmet and viewed or flew through portions of the reconnaissance scenario area of operations. A programmer introduced chromatic changes on-line to significant terrain, cultural, and ground targets. The observer judged the quality of the changes to the color or contrast until a satisfactory representation of the AN/AVS-6 imagery was obtained.

The HMD display consisted of the 11 elements shown in Figure 3. The display was programmed and integrated into a special imagery configuration that incorporated the NVG features described above. The HMD was located in the central portion of the NVG 40° circular field of view. All elements of the HMD display were dynamically updated as the pilot imposed control

Table 3

Descriptions of Target Site, Wire Obstacles, and Master Caution Events in the Reconnaissance Scenario

Target site, obstacle and event designation	Description	Terrain database location (UTM)
TS1	3 T-72 tanks in vegetated area	12S VN 3879 2931
TS2	3 T-72 tanks in vegetated area	12S VN 3979 4051
TS3	5 T-72 tanks in open desert near power lines	12S VN 4140 4119
TS4	5 T-72 tanks in open desert area draw	12S VN 4485 4635
TS5	3 trucks in open desert area draw	12S VN 4407 4964
TS6	3 T-72 tanks in vegetated area	12S VN 3678 5567
TS7	3 ZSU-23/4s in open desert area draw	12S VN 2993 6042
TS8	3 T-72 tanks in vegetated area	12S VN 2309 5650
TS9	5 T-72 tanks in open desert area	12S VN 2334 5148
WS1	Unmarked wire set No. 1 100 ft poles	12S VN 3051 3942
WS2	Unmarked wire set No. 2 150 ft towers	12S VN 3053 3244
WS3	Unmarked wire set No. 3 100 ft poles	12S VN 2901 2881
WS4	Unmarked wire set No. 4 150 ft towers	12S VN 2592 2380
MST1	Illumination of Master Caution Warning signal	12S VN 4147 4169
MST2		12S VN 3376 6019
MST3		12S VN 2274 5742
MST4		12S VN 2718 1392

inputs and flew the aircraft. The master caution warning indicator (MST) was illuminated as the aircraft passed over designated locations. The MST extinguished when the pilot pulled the weapon trigger on the cyclic stick, or after 20 sec elapsed, whichever came first. The MST instrument panel light, located on the instrument console approximately 21.5° below and 7.0° to the left of the pilot's straight-ahead and level line of sight, was masked for ANVIS-HMD users but was visible in the ANVIS-only condition.

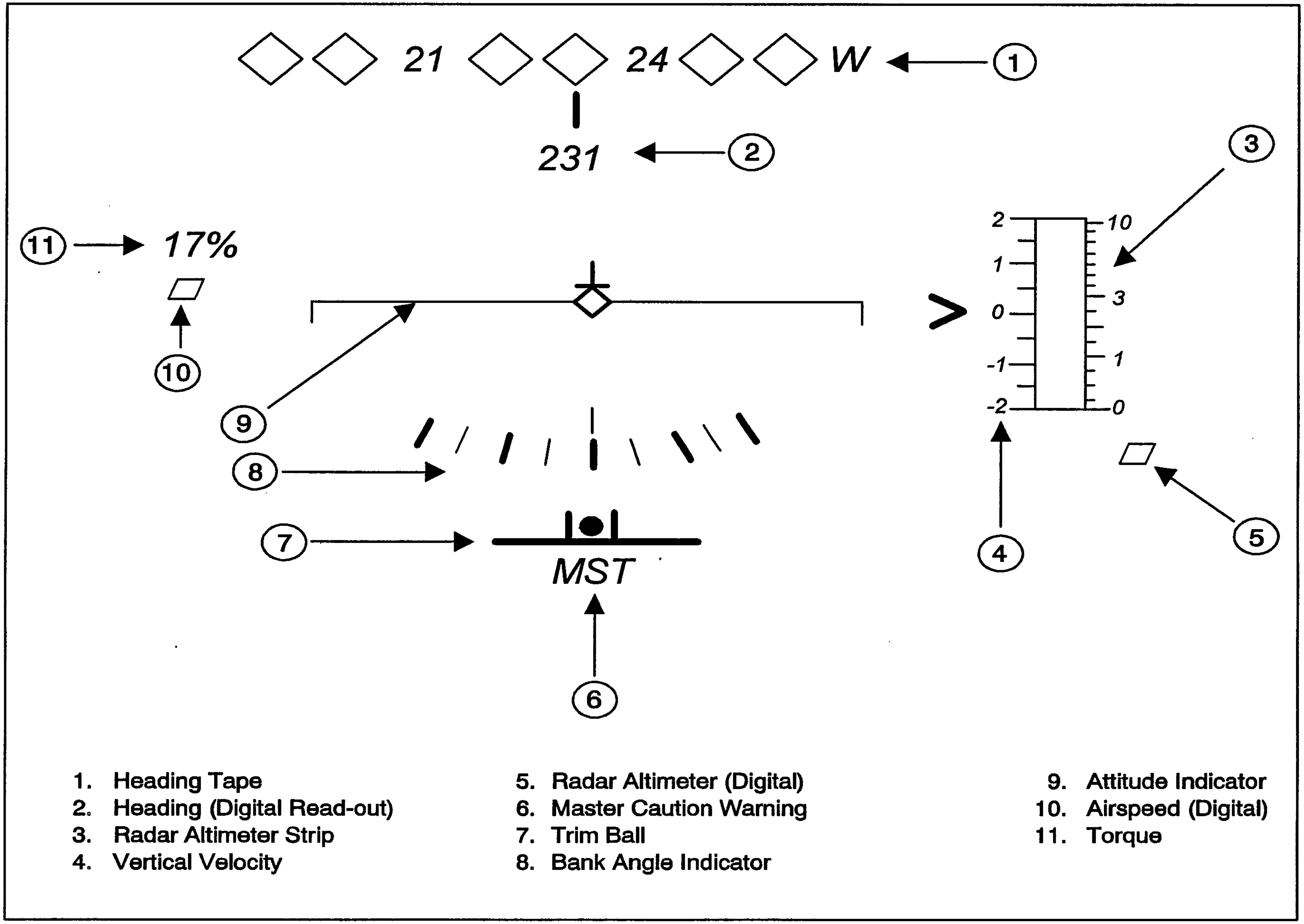

Figure 3. Instrument symbology of the ANVIS-HMD display.

Eye tracking data. Eye tracking data were obtained using two methods. The first used eye tracker instrumentation within STRATA that reads the relative location of the pupil center and the corneal reflection of an infrared light to determine eye position. The second method used a Sony black and white video monitor (model PVM-1271Q) that was substituted for the left EOS repeater monitor. The repeater monitor enables the experimenter to see the visual scene being viewed in the pilot's left background channel. A software modification in the simulator added eye tracker information in the form of a small cross to the video signal sent to this monitor. The cross changed position as the eye tracker monitored the movement of the pilot's eye over the visual scene. The picture on the monitor was recorded using a COHU 6415-2000/ES06 video camera and a Panasonic AG-6200 video recorder. Audio signals were amplified using an Archer 277-1008C amplifier.

Procedure

Helmet fitting. The STRATA imaging system requires an individually fitted helmet for each research subject. During the week prior to a pilot's scheduled experiment session, he or she reported for fitting of a helmet liner. This procedure entailed molding a foam helmet insert that was placed inside a FOHMD helmet used in the simulator. The foam insert assured that the helmet was maintained in a fixed position on the pilot's head. The completed foam insert was placed inside a helmet shell, and the left and right pancake window mounts were aligned in azimuth and elevation. This alignment ensured correct fusing of the left and right channel images when the complete optical imaging system was attached in the simulator.

Experiment orientation and cockpit familiarization. Subjects reported to the simulator facility and were briefed by the experimenter on the characteristics of STRATA and its intended uses for research. The experimenter then read a set of instructions appropriate for either the ANVIS-only or ANVIS-HMD condition. The STRATA description and experiment instructions are provided in Appendix A.

The voluntary nature of the subject's participation was explained, and the subject read and signed an informed consent form. The subject then completed a biographical questionnaire and provided handedness and sighting eye dominance data using instruments described in Morey and Simon (1991a). The biographical questionnaire and data collection form for handedness and sighting dominance are shown in Appendix B. The briefing and questionnaire data collection took approximately 30 minutes.

During the subject briefing, a site engineer prepared the simulator for the familiarization phase of the experiment. Settings and crosschecks were proceduralized in the form of a checksheet shown in Appendix C.

After the initial briefing, the pilot was seated in the pilot's station of the simulator. A site engineer or an experimenter then provided a cockpit orientation. The orientation covered (a) seat and pedal adjustment; (b) orientation to locations of the altitude, airspeed, vertical velocity, trim ball, torque, and artificial horizon indicators on the instrument panel; (c) location and purposes of nap-of-the-earth (NOE) flight, force trim and Digital Automatic Stabilization Equipment (DASE) switches on the instrument console and cyclic stick; (d) location of the weapons switch on the cyclic stick used to react to experimental events; (e) description and calibration of the g-seat; and (f) location of emergency switches. Instrumentation not necessary for flying the aircraft or conducting the experiment was not explained. The cockpit orientation also provided an explanation of the FOHMD imaging system. The pilot then donned the helmet and observed the background and inset channels. A site engineer made adjustments to fuse the background images and position the inset channel images. Mean time required to complete the cockpit orientation was 15.5 min (*SD* = 7.2).

Familiarization. All subjects were given two periods of flight familiarization during the morning. The first familiarization flight, completed by all subjects, was under daylight conditions. The second was under ANVIS-only or ANVIS-HMD conditions. No environmental effects (for example, wind, turbulence, cloud layers, reduced visibility), unusual aircraft system states, or consumption of fuel were imposed. Collisions with objects did not disable or crash the aircraft.

For the daylight familiarization, the aircraft was positioned at Falcon Field, and the pilot practiced hovering, traffic patterns, and takeoffs and landings. Pilots were told to monitor torque settings required for hovering, transition, and level flight and to accommodate to the sensitive control-input characteristics of the Apache helicopter. The pilot communicated with the experimenter or navigator over a hot-microphone intercom during both the familiarization flights and the subsequent reconnaissance mission. If the pilot reported that the optical systems had become misaligned, a flight freeze was imposed and the necessary corrections made.

Pilots were given no limitation on the amount of time they could practice flying under daylight conditions. The mean time spent in daylight familiarization was 25.2 min (*SD* = 4.5). Once the pilot had returned to the airfield and landed, he or she exited the cockpit for a rest and refreshment period.

During the rest period, site engineers loaded the familiarization scenario and converted the imagery to the ANVIS-only or ANVIS-HMD condition. The checksheet used for these changes is shown in Appendix C. For the ANVIS-HMD condition, cockpit instruments that duplicated the flight information in the HMD were concealed with black cut-outs. Once the pilot returned to the cockpit and donned the helmet, the background channels of the optical system were realigned to ensure a fused image.

Before beginning the familiarization scenario, the experimenter reviewed required tasks and procedures that had been described to the pilot during the orientation. These are listed in Table 4. Pilots responded to ground targets and master caution onsets by pulling a weapon trigger on the cyclic. Pilots also provided verbal reports to ground targets and wire obstacles as described in Table 4.

Table 4

Required Tasks and Standards

Task	Standards
Maintain airspeed	Maintain airspeed at 70 knots (tolerance = ± 10 knots)
Maintain altitude	Maintain altitude at 50-100 feet above ground level (AGL) (tolerances = 40, 110 ft AGL)
Follow flight path	Respond to heading and course directions from experimenter or navigator
Respond to master caution warning (MST)	Pull weapon system trigger on cyclic as soon as warning is detected on instrument panel for ANVIS-only condition or within HMD for ANVIS-HMD condition
Search for ground targets	Maintain scanning pattern from side to side
	Pull weapon system trigger when probable ground target first detected
	Once positive identification of ground target is made, verbally report number of targets observed, type of target, and clock position relative to current heading
Respond to wire obstacles	Negotiate wire obstacle according to local SOP. Verbally report wire obstacle encounter.

The familiarization scenario required the pilot to take off from Falcon Field and follow a predetermined flight path (described previously in the Scenarios section). The experimenter viewed the position of the aircraft on the tactical situation display and provided navigational information and warnings that target locations or master caution events were about to occur. The objective of identifying the upcoming targets was to aid the pilot in discriminating the stimulus features of targets. Likewise, identifying the imminent onset of master caution warnings ensured that the pilot had located the signal within his or her field of regard. Required responses were also monitored for correct execution. The experimenter issued corrections if (a) altitude dropped below 40 ft or exceeded 110 ft or (b) airspeed varied more than ± 10 knots. Performance data were not collected during the familiarization scenario.

Pilots were given the option of ending the familarization flight after they had flown through the ground target area, circled Canyon Lake, and had begun to retrace their route on First Water Creek. Pilots who reported fatigue or required adjustments to their helmets on this final leg of the familiarization scenario were permitted to end their familiarization flight. Others chose to complete the flight back to Falcon Field. Mean time spent in the ANVIS-only or ANVIS-HMD portion of familiarization was 40.7 min (SD = 7.2). The pilots then took a rest and luncheon break for 1.5 to 2.0 hours before the afternoon session.

Reconnaissance mission. The afternoon session began with a mission briefing given by an experimenter who also served as navigator for the reconnaissance mission. In addition to an air mission order, the pilot was provided a 1:250,000 scale Joint Operations Graphic map (Defense Mapping Agency Series No. 1501 Air) of the area of operations. The map was annotated with an overlay that showed air corridors, the forward line of troops (FLOT), start and release points, and air control points. The pilot was warned that wire obstacles would be encountered, but the specific locations of the wire obstacles were not provided on the briefing map. Required tasks were reviewed with the pilot. The pilot was reminded to use scanning techniques as required with NVGs.

During the briefing, site engineers used the ANVIS-only Reconnaissance Mission or ANVIS-HMD Reconnaissance Mission checksheets shown in Appendix C to ensure that the reconnaissance scenario had been loaded and the correct simulator conditions were established. Once the pilot returned to the cockpit and donned the helmet, he or she observed the ANVIS-only or ANVIS-HMD image for correct alignment; adjustments were made if required. The eye tracking system was also aligned.

For subjects in the ANVIS-HMD condition, selected eye position locations on the HMD were recorded to aid scoring of eye tracking data. The procedure entailed positioning the helicopter to face a hangar wall so that the pilot observed a uniform background surface. The pilot then fixated on a series of 18 points on the HMD that were either the center of mass of HMD elements (e.g., the center of the torque reading) or one of the corners of the rectangles forming the heading strip or vertical speed/altitude strip indicators (see Figure 3). The order of fixations was the same for all subjects. The experimenter told the pilot which point to fixate. The subject verified that he or she was looking at that point and held the fixation for approximately 3 sec. During the fixation period, azimuth and elevation readings were collected by the simulator's data recording facility at a rate of 60 Hz.

The navigator then repositioned the helicopter near the active runway and turned control of the airship over to the pilot. The pilot took off and established an initial heading. For this experiment, the pilot did not self-navigate by using the AH-64 navigational systems. Instead, the pilot responded to heading changes (i.e., "turn right and establish a heading of 315") issued by the navigator who monitored mission progress on the tactical situation display. The navigator provided heading corrections that directed the pilot towards waypoints and brought the helicopter into the vicinity of targets.

The navigator also informed the pilot when the airspeed or altitude exceeded the standards used in the familiarization scenario. The warnings consisted of a statement that (a) airspeed or alititude was either too high or too low or (b) reminded the pilot of what the airspeed or altitude standards were. The navigator's altitude, airspeed, and heading instructions were intended to direct the pilot's attention to the appropriate instruments (especially the HMD symbology in the ANVIS-HMD condition). However, the navigator did not forewarn the pilot that targets were coming into view, that master caution warnings were about to appear, or that power poles and wires were in the flight path.

The navigator maintained a log of target identifications, false detections of targets, and altitude and airspeed warnings issued to the pilot. This log sheet is shown in Appendix D. Once the pilot had reached the release point, the navigator turned on the video recorder to record eye tracking information which included power pole and wire areas and the FARP approach and landing as the pilot entered the final leg of the mission.

At the completion of the mission, either the navigator or experimenter debriefed the pilot on the experiment. Questions used in the structured interview are provided in Appendix E.

STRATA eye tracker scoring procedure. Scenario run-time eye tracking data were collected on all pilots, but only the ANVIS-HMD pilots completed a registration procedure to map this data onto the 11 HMD symbology elements in the field of view (see Figure 3). Analysis of their run-time eye tracking data first required developing individual scoring templates for each pilot using the ANVIS-HMD registration data. The run-time data were then compared to the pilot's templates to determine if the eye was positioned on a particular element of the HMD.

A preliminary analysis was conducted to determine if the eye tracking registration data were sufficiently accurate for scoring purposes. For each of the 12 ANVIS-HMD users[3], the registration data consisted of azimuth and elevation values (x and y coordinates) collected at 60 Hz for 2 to 3 sec as the pilot fixated on a specific symbology location. This fixation resulted in approximately 120 to 180 pairs of x and y coordinates. The mean x and y coordinates for each of the 18 registration points were computed. A trimmed mean set at a value of 5% was used to eliminate outliers, providing a more reliable estimate of the mean x and y coordinates for a fixation point.

For each pilot, the 18 pairs of mean x and y values were plotted on x-y coordinates. The resulting figure was inspected to determine if the spatial layout of the plotted points provided a reasonable approximation of the layout of the ANVIS-HMD symbology. An analysis of the ANVIS-HMD registration data then was conducted to obtain scoring templates for each display element. An individual set of scoring templates was constructed for each pilot. These templates were either a set of x and y values defining the corners of rectangles around objects, such as the heading tape and vertical speed indicator/altimeter strip, or a single pair of x and y values defining the center of a circle positioned over a single element, such as the trim ball. Scoring of scenario run-time eye tracking data entailed comparing a pair of x and y coordinates with the coordinates of each of the templates. Values falling on the borders of the template or within the template were scored as belonging to the corresponding HMD symbology element. Values falling outside all of the templates were scored as belonging to OTW scans or fixations.

The analysis of the registration data used the previously calculated mean x and y values, together with the x and y standard deviations. In the case of a circular template, the mean x and y coordinates established the center of a circle with the radius set at one standard deviation. The resulting circle had a diameter of approximately 1° which coincided with the 1° level of accuracy for the STRATA eye tracker. Circular templates were defined for the digital heading readout, digital radar altimeter, trim ball, master caution indicator, center of the attitude indicator, and airspeed. Because the (a) master caution and trim ball and (b) airspeed and torque circular templates showed considerable overlap, a scoring rectangle was defined for each of these pairs of elements. Scoring templates for both the heading tape and the vertical speed indicator (VSI)/altitude tape were

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[3] One of 13 pilots assigned to the ANVIS-HMD condition was a pretest subject whose data were not analyzed.

also rectangles. Dimensions of scoring rectangles were increased by one standard deviation from the x and y mean values defining their corners.

Scenario run-time eye tracking consisted of data collected at 60 Hz for approximately 8 min. Using the pilot's set of scoring templates, successive pairs of x and y coordinates from the pilot's run-time data set were evaluated for assignment to one of the seven ANVIS-HMD elements or to the non-HMD category. The localization data did not differentiate between saccades (i.e., rapid eye relocations), other forms of eye movements, such as vergence and smooth pursuit, and fixations at particular points in the ANVIS-HMD scoring areas. A fixation was determined within a scoring area by counting the number of successive x and y values that remained the same before a change in values signaled the beginning of an eye movement from that location. Each set of x and y values represented a location measured at a 17 msec interval. The minimum duration of a fixation was set at 85 msec (cf, Karsh & Breitenbach, 1983) and the maximum at 1500 msec. The maximum encompassed the fixation times of 400 to 600 msec observed in reading map symbols (Antes, Chang, Lenzen, & Mullis, 1985) and the 1500 msec durations observed in picture viewing (Gould, 1976).

Results

Results are first presented with respect to experimental group and experience level differences among major performance measures. An examination of these measures from an individual differences perspective is then reported. This approach used demographic data and selection of the most and least successful aviators to examine performance differences. All statistical analyses were completed using the Statistical Package for the Social Sciences Version 4.0 (SPSS/PC+; Norusis, 1990).

Flight Performance

Airspeed and altitude were recorded every 5 sec between the SP of the mission and termination of the mission at the FARP. Means and standard deviations (variability) were computed on the approximately 200 airspeed and altitude readings obtained for each subject. These means and standard deviations were then averaged over the 25 subjects. These results are shown in Table 5. Each of the four measures were analyzed with a condition (ANVIS-only and ANVIS-HMD) by experience (high and low) two factor between subjects analysis of variance (ANOVA). No significant interactions or main effects were obtained for differences between the ANVIS-only and ANVIS-HMD groups or the high and low experience groups, for either mean airspeed or altitude (all F (1, 21) $\leq$ 1.63, p > .05). Likewise, no interactions or main effects were obtained for differences between the ANVIS-only and ANVIS-HMD groups or the high and low experience groups, for variablility of airspeed or altitude (all F (1, 21) $\leq$ 1.34, p > .05).

Table 5

Means and Variability (Standard Deviations) of Airspeed and Altitude for Experimental Groups and Two Levels of Experience

	ANVIS-only		ANVIS-HMD		
Measure	Low experience	High experience	Low experience	High experience	Total sample
Airspeed					
Mean	69.5	72.3	71.0	72.0	71.2
Variability	11.6	10.5	10.0	11.5	10.8
Altitude					
Mean	82.1	80.3	81.5	79.8	80.9
Variability	37.1	32.8	34.0	36.0	34.9

Note. Units of measure: airspeed = knots; altitude = ft above ground level.

Overall, pilots maintained an average airspeed of 71.2 knots, very close to the required standard of 70 knots. Altitude was also maintained within the required limits of 50 to 100 ft above ground level (AGL) as shown by the overall average altitude of 80.9 ft. Ability to control the aircraft, as measured by the variablility of airspeed and altitude, did not vary significantly between experimental groups or experience levels.

Target Detection

Target detection performance was assessed by determining (a) the number of target sites detected, (b) the percentage of target sets correctly identified of the sites actually detected, and (c) false alarm rate. Maximum possible score for target site detections was nine. Target sets correctly identified refers to the number (but not type) of targets pilots reported as appearing at a target site (see Table 3). False alarm rate is the ratio of incorrect site detections to correct site detections. Target detection means, percentage of correct detections, and false alarm rates are shown in Table 6. A two-factor experimental conditions by experience level between subjects ANOVA revealed no significant differences for mean target sites detected (all F (1, 21) $\leq$ 1.92, $p > .05$), for percentage of target sites correctly identified (all F (1, 21) < 1), or false alarm rate (all F (1, 21) < 1). Regardless of experience level, ANVIS-HMD users did not reveal any statistically significant advantage in detecting or identifying targets as hypothesized. However, there was an indication that high experience aviators have more difficulty in target detections when using the ANVIS-HMD.

Table 6

Mean Number of Target Sites Detected, Percentage of Target Sets Correctly Identified, and False Alarm Rates by Experimental Group and Levels of Experience

	ANVIS-only		ANVIS-HMD		
Measure	Low experience	High experience	Low experience	High experience	Total sample
Mean target sites detected	6.0 (1.5)	5.5 (2.3)	5.4 (2.2)	3.7 (2.5)	5.2 (2.2)
Percentage of targets correctly identified	82	83	71	82	79
False alarm rate	.15	.22	.27	.27	.23

Note. Numbers in parentheses are standard deviations.

Whether ANVIS-HMD users detected targets sooner was examined using the range-to-target detection data. Greater detection range is equivalent to seeing a target sooner as compared with shorter range-to-target values. Range-to-target data were verified by examining absolute bearing to target at the point that a pilot signaled a target detection. Bearing values that revealed responses generated after the pilot had passed a target site were eliminated. Means and standard deviations of detection ranges are shown in Table F-1 in Appendix F.

Although no pilots detected all of the target sites, 10 pilots detected at least 77% of the sites. Three target sites had unusually low rates of detection. Two sites (T3 and T6) were difficult to see because of terrain contours, and the third (T2) was close to power lines (not those deliberately placed in the flight path for the final leg of the mission). Pilots tended to focus attention on the power lines as they maneuvered through the target site area as indicated by their statements to the navigator. With the exception of sites T2, T3, and T6, no patterns of failure-to-detect were established. However, the target detection data contained some missing sites for all subjects making it impossible to conduct a repeated measures or mulitivariate ANOVA on the range-to-target detection data.

As an alternative to one of these omnibus analyses, six experimental condition by experience level between subjects ANOVAs were conducted on each set of target site range-to-target data. The three target sites noted above were not analyzed. Results of the ANOVAs are shown in Table F-1. To offer some statistical control on the number of comparisons assessed, significance level for any test of main effect or interaction was set at $p < .0028$ to reflect the 18 single degree of freedom main effect and interaction comparisons represented by the 6 ANOVAs (.05/18 = .0028). Using this criterion, no statistically significant effects for experimental condition or experience level were obtained. The ANVIS-HMD users were not shown to detect targets faster than non-users.

Reaction Times to Master Caution Warnings

The distribution of reaction times to master caution warnings was highly skewed to the right for all four occurrences of the warning. The skewness was due to a few long response times (7 to 19.5 sec), and in three instances assigning a maximum score of 20 sec to a subject who did not respond to the warning signal. In addition to the high degree of skewness, variances tended to be approximately equal to the means. These distribution characteristics suggested a logarithmic transformation of the data prior to performing an analyisis of variance (Snedecor & Cochran, 1967, p. 329). A two factor between subjects (experimental condition and experience level) and one factor within subjects (trials) ANOVA was performed on the transformed data. The ANOVA results are shown in Table 7. Figure 4 depicts the mean response times expressed as geometric means (i.e., antilogarithms of the transformed data means).

Table 7

Summary of Analysis of Variance of Master Caution Warning Response Times

Source of Variation	*SS*	*DF*	*MS*	*F*	*p*
Between subjects					
Within cells	3.12	20	.16		
Experimental Condition (C)	1.08	1	1.08	6.90	.016
Level of Experience (E)	.12	1	.12	.76	.394
E x C	.43	1	.43	2.75	.113
Within subjects					
Within cells	4.12	60	.07		
Trials	.14	3	.05	.67	.571
C x T	.69	3	.23	3.35	.025
E x T	.16	3	.05	.75	.525
C x E x T	.47	3	.16	2.26	.091

A significant main effect of reaction time to master caution warnings was obtained for experimental condition (ANVIS-only versus ANVIS-HMD), $F\ (1,20) = 6.90$, $p = .016$, as well as a significant experimental condition by trials interaction, $F\ (3, 60) = 3.35$, $p = .025$. Tests of simple main effects revealed that

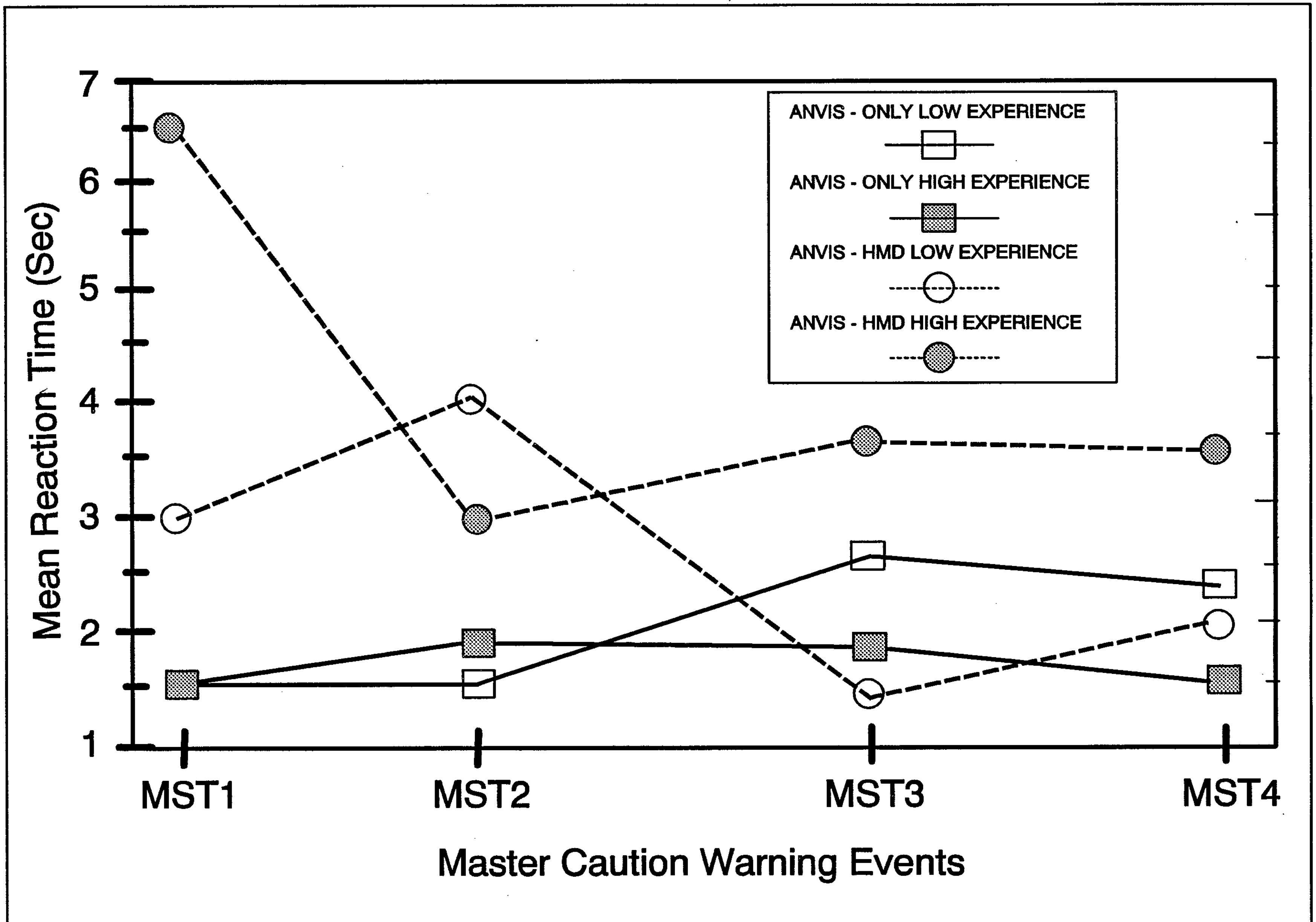

Figure 4. Mean reaction times to master caution warning onset.

the ANVIS-HMD group had significantly longer response times for the first master caution warning, F (1,60) = 7.36, p < .01, but that by the final master caution warning, their response times were equivalent to those of the ANVIS-only group, F < 1.

Collisions with Wires and Other Objects

The simulator recorded collisions with terrain features (such as trees), objects (such as buildings) and wires (WS1 through WS4). Collisions did not disable the aircraft. Eight pilots accounted for 13 obstacle strikes. A crosstabulation of pilots scoring one or more collisions, categorized by experimental condition and experience level, is shown in Table 8. No statistical differences were found for strikes by either experimental condition or level of experience, χ^2 (1, N = 8) = 2.88, p = .089.

Table 8

Number of Pilots Involved in Collisions Categorized by Experimental Condition and Experience Level

Experimental condition	Low experience	High experience	Total
ANVIS-only	3	0	3
ANVIS-HMD	2	3	5
Total	5	3	8

The type of object struck is shown in Table 9. Three pilots struck the same kind of object twice, and one pilot struck two kinds of objects. The ANVIS-HMD users had a distinct advantage in avoiding significant obstacles as evidenced by no strikes of wire obstacles or trees enroute. However, the ANVIS-HMD equipped pilots were at a disadvantage in approaching and landing into a confined area. On the other hand, ANVIS-only pilots were responsible for all recorded wire obstacle and tree collisions. The ANVIS-HMD user who struck buildings at the airfield did so at the beginning of the reconnaissance mission. However, many pilots showed instability in hover, taxiing, and take-off during the first few minutes of the reconnaissance flight.

Approach into a Confined Area

The pilots' approach and landing into the FARP provided data on approach and landing into a confined area. Altitude, airspeed, and time data were collected at a rate of 30 Hz when the aircraft crossed a boundary at 200 m from the center of the FARP. Although these data were collected on all subjects, due to technical problems, data for some subjects were not collected correctly.

Table 9

Type of Objects Struck Categorized by Experimental Group

Experimental group	Trees at FARP	Wire set	Trees enroute	Buildings at airfield
ANVIS-only		24_L, 24_L, 26_L	15_L, 15_L, 24_L	
ANVIS-HMD	3_H, 3_H, 7_H, 8_H, 27_L			25_L, 25_L

Note. Numbers in cells are subject number. Subscripts: L = Low experience, H = High experience.

For other subjects, differentiating when the subject had completed one or more initial approaches and had begun the final approach was difficult to establish. Data for these subjects were not analyzed. Usable data were obtained for 12 subjects (7 ANVIS-HMD and 5 ANVIS-only pilots). For these subjects, the landing was considered to have terminated when altitude reached 0 ft and airspeed was less than 2 knots.

Because altitude data were collected 30 times per second, values of "instantaneous" vertical speed or rate of descent (in ft/sec) were computed by taking the difference between successive pairs of altitude measures (in feet) and dividing by .03333 sec. The mean of these "instantaneous" values was then computed. The mean of the "instantaneous" values of airspeed (in knots) was computed by using the airspeed values that were also collected at 30 Hz. Table 10 shows the means of forward airspeed and vertical speed (rate of descent) for the ANVIS-only and ANVIS-HMD groups.

Table 10

Mean Vertical Speed (Rate of Descent) and Forward Airspeed on Approach to a Confined Area

	ANVIS-only		ANVIS-HMD		
Measure	Low experience	High experience	Low experience	High experience	Total sample
Mean vertical speed (ft/sec)	4.3 (3.2)	2.7 (1.5)	1.5 (0.7)	2.4 (1.0)	2.6 (1.7)
Mean airspeed (knots)	25.4 (4.8)	19.6 (13.2)	18.3 (5.1)	13.6 (5.0)	18.7 (8.6)

Note. Numbers in parentheses are standard deviations.

An experimental condition by experience level between subjects multivariate analysis of variance was conducted using airspeed and vertical speed as dependent variables. No significant effects were found for experimental condition, Wilks $\Lambda = .723$, $F\ (2,\ 7) = 1.34$, $p = .32$, experience level, Wilks $\Lambda = .891$, $F\ (2,\ 7) = 0.43$, $p = .67$, or the experimental condition by experience level interaction, Wilks $\Lambda = .806$, $F\ (2,\ 7) = 0.84$, $p = .47$.

Individual Differences

Performance measures were examined to determine performance profiles of the most and least successful aviators. To differentiate these two groups, seven performance measures were selected: airspeed variability, altitude variability, response time to the first master caution warning, number of target sites detected, accuracy of target identifications, false alarm rate, and number of obstacle strikes. For each variable, all 25 aviators were rank ordered from most to least successful. Most successful was defined as (a) low values for airspeed and altitude variability, reaction time to master caution warning, false alarm rate, and obstacle strikes and (b) high values for number of target sites detected and target identification accuracy. The 7 ranks assigned to each aviator were then averaged, and the entire sample of 25 aviators was rank ordered with respect to the average rank score. The five highest ranking aviators (80th percentile) were classified as the most successful aviators, and the lowest five (20th percentile) the least successful aviators. Mean or total values of the seven selection variables for the two success groups are shown in Table 11. Mean time spent in practice and familiarization also is shown. This was not used for aviator ranking because it could not be determined *a priori* how practice time would be related to subsequent performance.

The data in Table 11 show that the most successful aviators have a clear advantage in their ability to control the simulated aircraft, avoid obstacles, and react to the initial appearance of the master caution signal. With respect to searching for targets, the most successful aviators correctly identified more targets in detected sites but overall had a somewhat lower number of target site detections. This could have been due to a performance trade-off between piloting the aircraft and performing the search task. Negative correlations of airspeed and altitude variability with number of target sites detected would reveal such a trade-off. However, correlation analyses of these variables completed on the entire sample of 25 pilots and the success subsamples revealed no statistically significant correlations. Finally, the most successful aviators elected to spend less time in practice and familiarization flying than did their less successful counterparts.

Once aviators were differentiated with respect to the major performance variables, values of categorical variables (such as

Table 11

Mean Performance Measures of Most and Least Successful Aviators

	Group Means			
Performance measure	Total sample (N = 25)	Most successful aviators (n = 5)	Least successful aviators (n = 5)	Performance advantage of most successful aviators (% difference)
Airspeed variability (knots)	10.8	9.0	14.5	61
Altitude variability (ft)	34.9	29.9	40.6	36
Reaction time to first master caution (sec)	4.2	1.5	6.2	303
Number of target sites detected	5.2	5.6	6.2	-19
Percentage of correct target identifications	79	88	62	26
False alarm rate	0.2	0.3	0.3	0
Number of obstacle strikes[a]	13	0	4	
Practice/famil-iarization time (min)	65.9	58.2	70.0	20.3

[a] Row entries are total counts.

membership in experimental groups) and individual characteristics (such as experience level and eye dominance) were tabulated. These data are shown in Table 12. The comparison of most and least successful aviators reveals that only 1 in 5 of the most successful aviators was an ANVIS-HMD user. In contrast, 3 in 5 of the least successful aviators used the ANVIS-HMD. With respect to controlling the aircraft, avoiding obstacles, reacting to the master caution, and searching for targets, the performance advantages shown by the most successful aviators cannot be attributed to their use of the ANVIS-HMD.

The differences between the most successful and least successful aviators are less distinct with respect to experience

Table 12

Values of Categorical Variables for the Most and Least Successful Aviators

Characteristic	Most successful aviators (n = 5)	Least successful aviators (n = 5)
Experimental condition	ANVIS-only = 4 ANVIS-HMD = 1	ANVIS-only = 2 ANVIS-HMD = 3
Experience level	Low = 3 High = 2	Low = 2 High = 3
Duty position	IP = 2 Aviator = 3	IP = 1 UT = 1 Aviator = 3
Eye dominance	Left = 1 Right = 4	Left = 1 Right = 4
Sex	Female = 0 Male = 5	Female = 1 Male = 4
Primary aircraft	UH-1 = 2 UH-60 = 3	UH-1 = 3 UH-60 = 1 OH-58 = 1

Note. IP = Instructor Pilot, UT = Unit Trainer.

level, primary aircraft, and sex. The trend, however, was that aviators whose primary aircraft was the UH-60 and who had less experience (i.e., one year or less as a rated aviator) performed with higher levels of proficiency. In fact, all three UH-60 pilots in the most successful group were inexperienced pilots[4]. These findings may be attributed to the greater similarity of the UH-60 aerodynamics to that of the simulated AH-64 Apache. Less experienced aviators also may be able to more rapidly adapt to the AH-64 aerodynamics because of less ingrained input-control behaviors on their primary aircraft. In addition, these pilots may have benefited from the fact that the UH-60 is the only

[4] To examine the possibility that the pilot's primary aircraft (e.g., UH-60) might be a more significant influence on performance than experience level, airspeed variability, altitude variability, and number of target detections were analyzed with three ANOVAs incorporating primary aircraft as a factor. Data from the entire sample of subjects were examined. The experimental condition (ANVIS-only and ANVIS-HMD) by primary aircraft (UH-1, UH-60, and other) ANOVAs revealed no significant main effects or interactions (all Fs $\leq$ 1.20) for any of the three dependent variables. Because the pilot's primary aircraft revealed no relationship with these key performance measures, no further analyses of this factor were conducted.

helicopter (of the primary aircraft flown by the subjects in this experiment) that uses a visual simulator for training. Finally, the most successful group of aviators was entirely male and had the same proportion of aviators and trainers as the least successful group.

The failure of the least successful aviators to use the ANVIS-HMD effectively might be attributed to the fact that two of the three ANVIS-HMD users in this group were highly experienced UH-1 pilots. The marked dissimilarities of the AH-64 from the UH-1 with respect to control characteristics might be the cause of the poorer flight performance of these two pilots. Their difficulty in controlling the aircraft may have negated any benefit derived from presence of the HMD symbology. However, two of the pilots in the most successful group were also highly experienced UH-1 pilots who achieved superior performance. Neither of these pilots used the ANVIS-HMD. So, either the ANVIS-HMD could not compensate for control difficulties, or it actually interfered with achieving satisfactory performance.

The proportion of left and right eye dominant aviators in the two success groups was identical. This is not surprising because the expectation was that sensitivity to eye dominance differences would be evident only within the ANVIS-HMD group. Recall that the ANVIS-HMD was presented to the right eye, which may or may not have been the sighting dominant eye. To examine the issue of eye dominance, Pearson correlations were computed for the 13 ANVIS-HMD users to determine if the eye viewing the ANVIS-HMD symbology was related to performance differences. The results are shown in Table 13, together with correlations for eye dominance and handedness computed for the entire sample of 25 pilots. The only performance measure significantly associated with the ANVIS-HMD user eye dominance was target false alarms ($r = .57$); more false alarms were registered by right-eye dominant pilots. For the entire sample of pilots, a significant relationship was obtained between eye dominance and collisions ($r = .73$), with fewer collisions occurring with right-eye dominant pilots.

Handedness was significantly correlated with one performance measure for the entire sample of pilots. Reaction time to the first master caution warning revealed a significant negative correlation with handedness ($r = -.43$); that is, as hand preference became more distinctly right-handed, reaction time decreased. This relationship was considerably stronger in the ANVIS-HMD users ($r = -.72$, $p = .006$). In addition, handedness was signficantly correlated with eye dominance for the entire sample of pilots, $r = .43$, $p = .036$, which is consistent with prior laterality research results (Morey & Simon, 1991a,b).

Eye Tracking and Visual Scanning Data

Two types of eye tracking analyses were conducted. The first used data from the eye tracking system integral to STRATA for

Table 13

Correlations of Performance Measures with Eye Dominance and Handedness

Performance measure	Eye dominance[a]		Handedness[b]
	ANVIS-HMD users (n = 13)	All pilots (N = 25)	All pilots (N = 25)
Mean airspeed	.11	-.11	.34
Airspeed variability	-.18	.01	.03
Mean altitude above terrain	.03	.19	.12
Altitude variability	-.08	.15	.01
Target sites detected	.25	.27	-.02
Targets correctly identified	-.23	-.34	-.21
Target false detections	.57*	.34	-.01
Master caution #1 reaction time	-.19	-.11	-.43*
Master caution #2 reaction time	.06	.07	.09
Master caution #3 reaction time	-.14	-.07	-.22
Master caution #4 reaction time	.13	.11	-.12
Number of object collisions	-.61[c]	-.73*[d]	-.25[d]
Mean vertical velocity into FARP	-.21[e]	.16[f]	.35[f]
Mean airspeed into FARP	.48[e]	.16[f]	.29[f]

[a] on a scale where 1 = left and 2 = right.
[b] on a scale of 1 to 5 where 1 = strong left and 5 = strong right.
[c] n = 5 (see Table 8).
[d] n = 8 (see Table 8).
[e] n = 7 (see page 34).
[f] n = 12 (see page 34).
*$p < .05$

analysis of ANVIS-HMD localizations and fixations. The second analysis used videotapes of a monitor showing one of the FOHMD helmet visual channels onto which a small white cross had been superimposed. The cross indicated the center of the pilot's pupil relative to the visual scene.

STRATA eye tracking data. A preliminary analysis was conducted to determine if the eye tracking registration data were sufficiently accurate for scoring purposes. This analysis revealed that for 7 pilots, the plots of the 18 registration data points bore insufficient resemblance to the spatial layout of the elements of the HMD. Most frequently occurring errors were (a) severely skewed endpoints representing the corners of the heading tape and vertical speed indicator/altimeter strip rectangles, (b) elements displaced from their expected locations, and (c) anomalous data, such as duplicated or unrealistically large values. Data from these seven pilots were eliminated.

For the remaining five pilots, an analysis of the ANVIS-HMD registration data was conducted to obtain scoring templates for each display element. An individual set of scoring templates was constructed for each of the five pilots. Using the pilot's set of scoring templates, successive pairs of x and y coordinates from the pilot's run-time data set were evaluated for assignment to one of the seven ANVIS-HMD elements or to the non-HMD category. Data from one of the five pilots showed only 3.2% of the localizations in the HMD. Given that these data were well outside the parameters established by the other aviators, they were considered as outliers and possibly anomolous for technical reasons; therefore, these data are not reported. A summary of the eye tracking data from the remaining four pilots is shown in Table 14.

The data reveal that between 12 and 28% of the time, or on average 17.9% of the time, the pilots localized their eyes on flight information areas of the HMD. The most frequently localized area of the HMD was the vertical speed indicator/ altimeter strip area, which was 9.7% of the time. The data do not permit determining the relative frequency of looking at each element of this pair. The next most frequently localized area (4.9%) was the heading tape. If eye localizations of these indicators are combined with those of corresponding digital readouts, then the frequencies of localizations of altitude and heading information are 9.8% and 5.8%, respectively. Localizing the eye on the airspeed and torque information area occurred 0.8% of the time, and on the trim ball and master caution area 1.0% of the time. The data in Table 14 also show considerable individual differences among the four pilots in frequencies of localizing the eye on various HMD elements.

The percentage of fixations occurring in the seven ANVIS-HMD information areas also is shown in Table 14. The objects fixated in the non-HMD areas (i.e., the OTW scene) could not be

Table 14

Percentage of Eye Tracking Localizations and Fixations Within and Outside ANVIS-HMD Elements for Four Pilots

	Pilot									
	A		B		C		D		Mean	
ANVIS-HMD element	Locali-zation	Fixa-tion	Locali-zation	Fixa-tion	Locali-zation	Fixa-tion	Locali-zation	Fixa-tion	Locali-zation	Fixa-tion
Heading tape	5.8	31.8	0.9	8.8	0.8	6.0	11.4	28.2	4.9	20.9
VSI/ altimeter	11.2	64.4	10.5	87.8	5.3	45.3	11.5	55.1	9.7	64.3
Digital heading	0.1	0	0	0	0.7	6.0	2.7	0.6	0.9	1.4
Airspeed/ torque	0.6	2.3	0.1	0.4	2.7	24.4	0.1	0	0.8	6.3
Bank indicator	0.3	0.8	0.1	0.4	0.1	0	1.1	0.6	0.4	0.6
Trim ball/ MST	0.2	0	0.4	2.5	2.3	18.4	1.2	15.4	1.0	6.2
Digital altimeter	0.3	0.6	0	0	0.2	0	0	0	0.1	0.3
Outside	81.5	nc	88.0	nc	88.0	nc	72.0	nc	82.1	nc
Time (min)	8.5	1.3	7.5	0.7	7.8	0.6	8.6	0.7	8.1	0.8

Note. nc = not calculated.

determined because they were dynamic. The distribution of fixation times for each of the four pilots is shown in Figure 5.

The percentage of time fixated on the seven HMD information locations generally corresponds to the percentage of time the eye was localized in those locations. However, fixations accounted for only 7 to 15% of the time the eye was localized in any of these areas. Of the time spent in fixation, the VSI and altitude tape area were clearly the region of most frequent fixation, averaging 64.3% of the time. For three out of four pilots, the heading tape was the next most frequently fixated area. Although the digital airspeed and torque area, and the trim ball/MST areas, were the third most frequently fixated areas on average, pilots showed individual differences in the pattern of distribution of fixation gazes in these two regions. The digital altimeter and bank angle indicator were the least frequently fixated areas.

The fixation data are consistent with the task demands of the situation. Pilots were flying at very low altitudes. Visual cues to distance above the ground were difficult to discern, as revealed in debriefing sessions. Pilots, therefore, had to rely on the radar altimeter and VSI information to remain above treetop level. More importantly, pilots were well aware of power lines in the area and were maintaining altitude to avoid that hazard. Forward motion and airspeed cues, in contrast, were much less ambiguous. This would account for much lower frequency of attending to the airspeed indicator. Heading constitued the next most frequently fixated area, consistent with the demands to remain on the flight path. Generally, pilots appeared to have ignored the digital altimeter and bank angle indicator. Information provided by these two instrument readings may have been more readily discerned graphically in the altimeter strip and actual OTW horizon, respectively.

The extent to which pilots fixated on two or more HMD elements in succession before transitioning to the OTW scene is shown in Table 15. In only 5.1% of the fixation periods did pilots fixate on two symbology elements, and rarely did pilots fixate on three elements before returning to the OTW scene. These data suggest that pilots avoided massing fixations on the symbology suite and adopted a strategy for switching between the symbology and the OTW scene.

The distributions of fixation times shown in Figure 5 reveal that fixations took on many values within the range of 85 to 1500 msec. The figure also illustrates distinct individual differences in the number of fixations produced by the four pilots, and to a lesser degree, differences in the range of their fixation times. For all the pilots, however, 75% of their fixations were less than 275 msec, or about a quarter of a second. With respect to longer fixation times, one pilot did not exceed 612 msec fixation time, and two pilots had only one occurrence each of a fixation

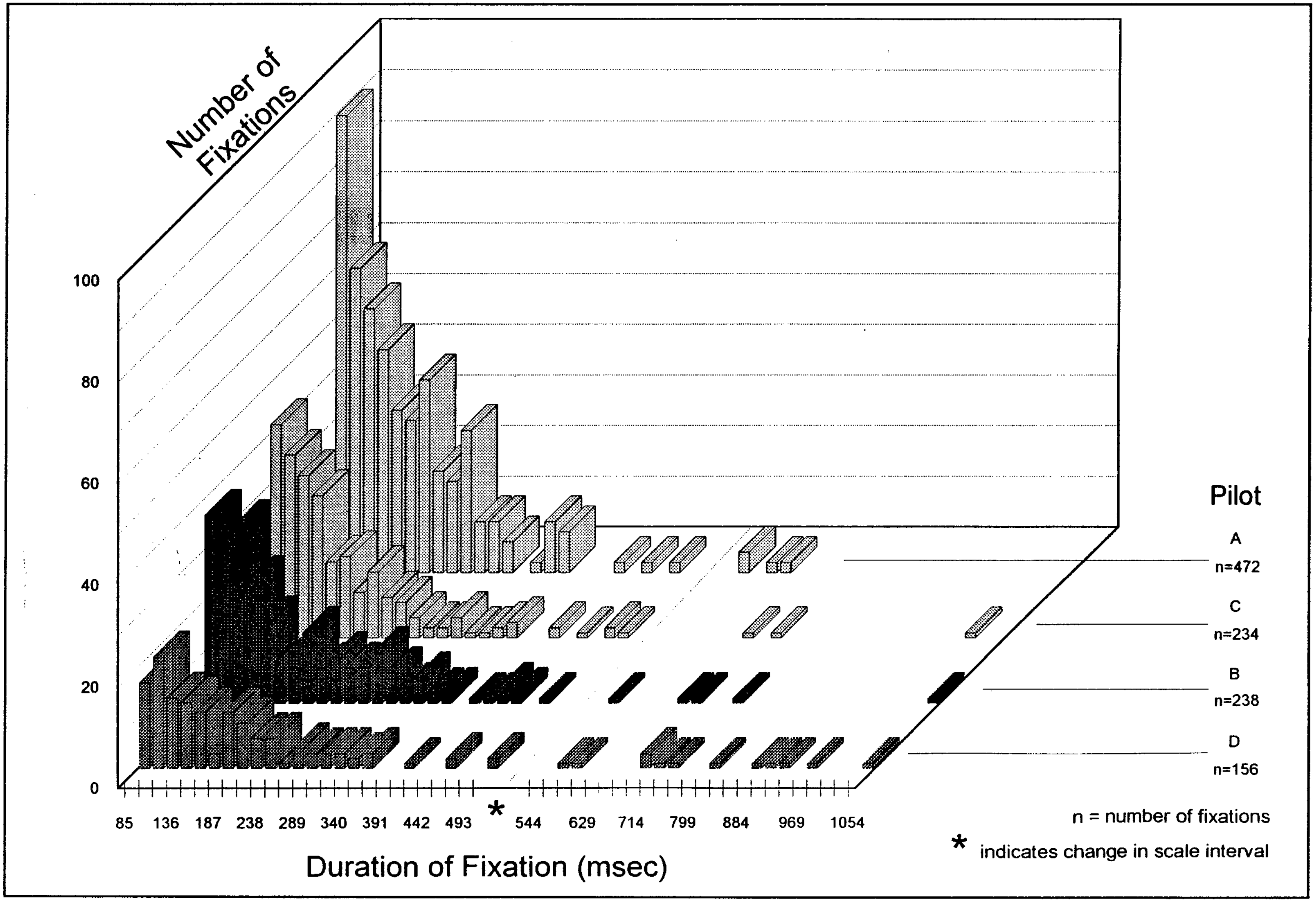

Figure 5. Distribution of eye fixation times on instrument elements of the ANVIS-HMD display.

Table 15

Percentage of Single and Multiple Fixations on HMD Elements before Transitioning to the OTW Scene

Number of HMD elements fixated	Pilot				
	A	B	C	D	Mean
1	92.8	98.3	94.4	92.7	94.6
2	6.8	0.8	5.6	7.3	5.1
3	0.4	0.9	--	--	0.3

in excess of one second. Six percent of the fixation times for Pilot D exceeded 1000 msec; most of these fixations were in the range of 1547 to 5000 msec, with two values in the 10,000 msec range. These latter two values are probably data collection errors, but the others may represent legitimately long fixations on the HMD elements. Because these fixation times in excess of 1500 msec may be questionable data, they were not included in the analysis or Figure 5.

Analysis of video eye tracking data. The videotapes of one of the image generator background channels, with the pilot's eye position represented by a small white cross superimposed on the scene, provided an additional source of information on what images the pilot was viewing and the position of his eye relative to the NVG circular mask. The mission segment that was recorded was the flight path through the area of four wire sets and into the FARP (see Table 1). Analysis of the videotapes required scoring by a project researcher who was familiar with the scenario and was an experienced helicopter pilot. During a preliminary analysis, this subject matter expert reviewed the tapes for potential information that would supplement performance measures obtained from STRATA. Once this information was determined, subjective scoring criteria were developed. The tapes were reviewed again, and each pilot's eye tracking and scanning behavior was evaluated. The assessments performed and their associated scoring criteria are shown in Table 16.

Of the recorded 99 out of a possible 100 encounters with wire obstacles (25 pilots times 4 wire sets), 8 failures to detect were observed. As shown in Table 17, three of these failures were attributed to pilots equipped with the ANVIS-HMD, and five to ANVIS-only users. Of the five ANVIS-only failures to detect, three were registered by one pilot. A chi-square analysis revealed no statistically significant differences in wire detections between the two groups. These video eye tracking data indicate that the incidence of pilot failure to detect wire

Table 16

Assessments and Scoring Criteria for Videotaped Eye Tracking Information

Assessment	Scoring criteria for each wire obstacle
Portion of the wire obstacle detected first	Poles (towers) or wires
Scanning patterns on detected wire obstacle	Fixation or scanning after detection
Assessment of adequacy of side-to-side scanning	Side to side scanning score during 1 min prior to passing wire set: Good: More than 2 scans/min Average: 1 or 2 scans/min Poor: Less than 1 scan/min
Percentages of time spent viewing OTW or cockpit instruments	Percentage of time eye tracker positioned in upper, middle, and lower portion of monitor image. Scoring interval: 30 sec prior to passing wire set

Table 17

Comparisons Between ANVIS-HMD and ANVIS-only Pilot Wire Obstacle Detections and Scanning Patterns

	Experimental group	
Eye tracking assessment	ANVIS-HMD	ANVIS-only
Obstacle detection		
Detected	48	43
Missed	3	5
Scan pattern		
Fixated	16	10
Scanned	32	33

Note. Tabled values are number of wire obstacles.

obstacles was higher than provided by the STRATA results reported earlier. The STRATA data (Table 9) showed that three wire strikes occurred, all of them attributable to ANVIS-only pilots. However, the STRATA data deal with actual collisions, and the current data encompass both collisions and near misses. Both the ANVIS-HMD and ANVIS-only pilots failed to detect wire obstacles between 6 and 10% of the time, but ANVIS-only pilots actually flew within the collision envelopes defined around the wire obstacles.

For the 91 detected encounters with wire obstacles, all pilots detected the power transmission poles or towers first. The scan pattern data in Table 16 show the number of pilots who remained fixated on the poles or towers as they approached the obstacles, and the number of pilots who established a scanning pattern over the complete obstacle--both poles and wires. ANVIS-HMD pilots remained fixated on 33% of the obstacles as compared to ANVIS-only pilots who remained fixated on 23% of the obstacles. However, there were no statistically significant differences between the ANVIS-HMD and ANVIS-only groups with respect to their frequencies of fixations and scanning when analyzed with chi-square.

Under NVG conditions, the field of view is significantly reduced. Moving the head from side to side is the primary method of compensating for this limitation. Systematically scanning the OTW scene within the goggles with eye movements is a second means. This movement of the eyes was assessed in two ways using the videotapes of eye tracking. The first assessment entailed rating the adequacy of horizontal scanning for 1 min prior to each obstacle encounter. The rating scale assigned 1 to good scanning, 2 to average, and 3 to poor. An overall scale was generated for each pilot by adding the scores across the detected obstacles. Cronbach's alpha for the scale was .91 indicating a high degree of within-subject consistency in scanning scores. The mean score for the ANVIS-HMD group was 2.4 and for the ANVIS-only group was 2.0. A t-test revealed no significant difference between the two groups, $t(22) = 1.26$, $p > .05$. Both groups demonstrated scanning behavior that scored in the average range.

The second assessment of scanning involved eye movements observed for 30-sec periods prior to passing the first and fourth wire sets. This assessment focused on vertical scanning using scoring criteria shown in Table 16. The results are shown in Table 18.

A two-factor analysis of variance with one between-subjects factor (ANVIS-HMD and ANVIS-only) and one within-subjects factor (middle and lower third) was conducted on the scanning data. Because of the high incidence of no scanning in the upper-third area (i.e., a large number of 0 scores), these data could not be included in the analysis. The analysis revealed a significant main effect for scanning area, $F\ (1, 17) = 121.80$, $p < .0005$, and a significant experimental group by scanning interaction,

Table 18

Proportion of Eye Scans in Three Areas of the Pilot's Field of View

Area of forward view	Experimental group	
	ANVIS-HMD	ANVIS-only
Upper third	2.5	0.5
Middle third (Horizon)	83.4	62.7
Lower third (including instrument panel area)	14.0	36.8

F (1, 17) = 23.54, p < .0005. The ANVIS-HMD pilots spent signficantly more time in the middle-third (horizon) area than the ANVIS-only pilots, as revealed by a test of simple main effects, F (1, 17) = 22.63, p = .0002. The middle area for the ANVIS-HMD pilots was the area containing the instrument symbology. On the other hand, the ANVIS-only pilots spent significantly more time viewing the lower-third area (i.e., below the horizon and into instrument panel area), F (1, 17) = 20.73, p = .0003. The somewhat larger percentage of time the ANVIS-HMD users spent above the horizon is probably the result of looking at information in the upper portion of the symbology suite.

The time that ANVIS-only pilots spent localized in the instrument area can be compared with the time ANVIS-HMD equipped pilots spent localized in the HMD symbology area: 36.8% of the time in the instrument area (Table 18) and 17.9% of the time in the instrument symbology area (Table 14), respectively. Half as much time appears to have been spent moving the eye over the instrument areas and obtaining instrument readings in the HMD condition. However, the ANVIS-only pilots were also able to see all the cockpit instruments, including those represented in the HMD symbology suite. Also, their eyes spent more time in transit between the OTW scene and the instrument area. Overall, the data seem to indicate more effective use of time in obtaining instrument information in the HMD mode than in the conventional look-down mode.

Discussion

The purpose of this experiment was to determine flight performance and low-level hazard avoidance effects when flight information was superimposed on NVG images. The combination of four factors distinguished this experiment from earlier studies that have explored HUD performance effects: superimposing HMD symbology on the ANVIS display, using rated pilots as the test subjects, execution of the experiment on a full-mission helicopter simulator, and performing operationally realistic tasks within a demanding mission scenario. These four features of the experimental situation provided the opportunity to examine performance issues specific to rotary wing operations and to conduct exploratory analyses of visual fixation and scanning behavior associated with HMD use.

The discussion of the results of this experiment are organized into three sections: The first section examines the overall flight performance results, the second discusses results relevant to flight safety, and the third and final section discusses results from an individual differences perspective.

Flight Performance

The reconnaissance mission flown by the pilots in this experiment required contour flight at altitudes of 50 to 100 feet AGL. Flying at this low altitude, just above treetop level, required pilots to maintain a large share of their time "head-up," that is, looking out the window. Remaining head-up was reinforced by the additional tasks of searching for ground targets and avoiding wire hazards. These situational demands created conditions for a variety of comparisons between the ANVIS-HMD and ANVIS-only users. Two of these comparisons were reflected in hypotheses that ANVIS-HMD users would demonstrate better control (i.e., less variability) of airspeed and altitude and detect more ground targets than the ANVIS-only group. With critical flight information superimposed on the field of view, the ANVIS-HMD users could remain almost exclusively head-up to monitor flight parameters while maintaining searches for terrain contour changes, targets, and hazards. However, the results revealed that the ANVIS-HMD users did not demonstrate any advantage in having their altitude and airspeed information superimposed on the OTW scene. Remaining head-up also provided no advantage in detecting ground targets, reporting the number of targets at a target site, or avoiding false reports of target sightings.

The definitive absence of any performance effects involving condition of viewing (ANVIS-HMD and ANVIS-only) and pilot experience level was revealed by main effect and interaction F ratios less than 1. Although statistically significant differences were absent from the results, the fact that the ANVIS-HMD did not impose any performance decrements is of considerable practical importance. In other studies that imposed symbology on a restricted field of view (e.g., Brickner & Foyle, 1990), performance decrements were observed in maintaining altitude and executing maneuvers. In contrast, ANVIS-HMD users in this experiment were as effective as pilots in the ANVIS-only mode. Noteworthy, also, is that the pilots using the ANVIS-HMD did not require any additional training or familiarization to achieve performance comparable to the baseline, ANVIS-only condition.

Experience level differences between recent IERW graduates and high time aviators and instructors were not associated with flying or target detection differences. Mean airspeed and altitude variability was lower (Table 5) and target detections were greater (Table 6) for low experience ANVIS-HMD users when compared to high experience users, which would suggest that the low experience aviators were more effectively using the display information. However, mean group differences are not supported by the analysis of variance results that demonstrated considerable overlap of the data distributions of the two groups. These results are in contrast to the findings of McAnulty et al. (1992), who found better monitoring of the symbology by inexperienced pilots, but superior performance in reacting to the OTW scenes by the experienced pilots.

The only factor that appeared to be susceptible to practice was reaction time to the master caution warning signals. The master caution signal was programmed to illuminate four times during the scenario. The ANVIS-HMD users showed significantly slower reaction times to the first signal onset as compared with the ANVIS-only group. This initial difference decreased after the first occurrence, until reaction time to the signal was equivalent for the two viewing conditions. Pilot experience level was not implicated in reaction time differences to the master caution warning onset.

The hypothesized faster reaction times to the master caution by the ANVIS-HMD pilots did not occur. This may have been because the master caution signal appeared approximately 21.5° below and 7.0° to the left of the pilot's straight-ahead and level line of sight for the ANVIS-only pilots. The light was relatively bright with respect to other instrument lights and was the only operative indicator on the top of the console. Its onset was quite noticeable because it was close to the OTW field of view and isolated from other indicators. Some pilots commented in the debriefing that the master caution symbol in the HMD might be more noticeable if it were positioned closer to the center of the symbology display.

No differences were hypothesized for rates of closure into a confined area. Pilots using the ANVIS-HMD were not expected to use the symbology for their approach, which was governed predominantly by visual cues. As predicted, both forward motion and rate of descent were equivalent for the ANVIS-HMD and ANVIS-only conditions. Because terrain and ground effect cues are not as pronounced in STRATA as they are in actual flight operations, it seemed reasonable that the ANVIS-HMD users would have shown some advantages. It is surprising, then, that reliance on the HMD's altitude and vertical speed indicators was not evidenced. As was the case with other performance measures discussed above, pilots' experience level was not a significant factor in approach and landing into a confined area.

Flight Safety

Of paramount importance to helicopter pilots is avoiding electrical transmission poles and wires. These are particularly dangerous obstacles because wires are difficult to detect even with warning markers placed on them. As a result, pilots have to remain vigilant for the unexpected appearance of wire obstacles. To create wire hazards for this experiment, specially designed power transmission towers and suspended wires were created in the terrain database. These wire sets adhered to power industry standards of appearance, height (100 and 150 feet), and separation. The wire sets were placed in the final leg of the mission, when pilots were expected to be moderately fatigued. The wire obstacles, extending well into the prescribed altitude, were expected to create an especially hazardous condition for all pilots. The hypothesis was, however, that ANVIS-HMD users would be better able to avoid collisions with these obstacles than their ANVIS-only counterparts.

The results supported the hypothesis only in a literal sense. No ANVIS-HMD users were involved in collisions with wires, in contrast to the ANVIS-only pilots who accounted for three wire collisions. However, videotapes of scanning behavior showed that both the ANVIS-HMD users and the ANVIS-only pilots failed to detect about 9% of the wire obstacles. When actual collisions are taken into account, the ANVIS-HMD pilots had three near misses as compared with two for the ANVIS-only pilots. The hypothesis of no collisions implies that the ANVIS-HMD users would be superior in both detecting and avoiding the obstacles; however, the near miss data indicate that the ANVIS-HMD was not instrumental in enhancing the pilots' detection and avoidance of the wire obstacles. The three failures to detect the wires could very well have resulted in wire strikes by the ANVIS-HMD users but by chance did not. Therefore, the hypothesis that the pilots equipped with the ANVIS-HMD would be better able to avoid wire obstacles was not supported.

This failure of the ANVIS-HMD users to have an advantage in detecting the wires may be explained in terms of scanning. The horizon area is where the wire obstacles would first come into view during level flight. For the ANVIS-HMD equipped pilots, this was the area of most frequent scanning (i.e., the middle third of the field of view), which was the region just above and below the horizon and at the center of the symbology suite. Fixation on the symbology located in this area was ruled out as a distracting factor because the STRATA eye tracking data did not show convincing evidence for prolonged fixation on the symbology. Fixation results are discussed later in this section.

The assessment of scanning adequacy carried out on the video eye tracking data also showed that the ANVIS-HMD users were scanning no better than their ANVIS-only counterparts. In part, the ANVIS-HMD pilots' failure to detect wire sets may have resulted from (a) physical masking of the wire by the attitude indicator, which extended horizontally at the level where the wires initially appeared or (b) reduced sensitivity to the low contrast wires due to the significantly brighter attitude indicator (or perhaps the entire HMD symbology suite). The video data offer some support for these possibilities by showing that all detected wire sets were detected at the pole rather than the wire. For the ANVIS-HMD users, the advantage of having the head up is necessary but not sufficient for more effective detection to occur. Whether more frequent scanning or a combination of horizontal and vertical scanning (above and below the attitude indicator) would increase the detection rate of the ANVIS-HMD users could be examined in future experiments.

The use of the ANVIS-HMD, however, was associated with collisions with trees during the final approach into a confined area (the FARP). ANVIS-HMD users registered five collisions with trees, whereas the ANVIS-only users registered none. The difficulty with the ANVIS-HMD may have been cluttering of the field of view with the instrument displays at a time when unobstructed vision was necessary. The approach into the FARP entailed descending over a forested area and proceeding through a narrow opening between trees to the landing area. During this approach and landing, the pilot experienced more visual clutter in the OTW scene (i.e., a densely forested area) than at any other time during the mission. Moveover, the pilot did not have the option of removing the symbology display that added to the clutter. Because the pilots were probably using primarily visual cues to negotiate an approach, the symbology would have been a decided disadvantage. Therefore, giving the pilot the option of turning the HMD off appears to be an important consideration in its effective use.

The difficulty four ANVIS-HMD users had with respect to striking trees on approach to the FARP contrasts with the fact that no ANVIS-HMD users struck trees while enroute. Trees represented the second most significant hazard after wires, and no pilots using the ANVIS-HMD were responsible for striking trees. On the other hand, three strikes against trees were recorded for the ANVIS-only pilots. This safety advantage for the ANVIS-HMD users during contour flight is not evident from the airspeed and altitude variability results discussed earlier. Although the ANVIS-HMD users did not demonstrate better aircraft control over the entire mission, evidently there were situations or incidents in which they were better able to maintain altitude above the trees.

Another safety issue that other HUD studies have identified is the phenomenon of cognitive capture. Cognitive capture refers to the tendency of the observer to abandon the division of attention between the HUD or HMD symbology and the OTW scene and to remain fixated on the symbology display. Reports of cognitive capture on symbology is provided in Weintraub et al. (1985) and Fisher et al. (1980), who noted pilots' failure to see an unexpected critical event: another aircraft entering the active runway during final approach. The original research design for our experiment called for one or more unexpected events to occur during the mission, such as another aircraft crossing the flight path. Cognitive capture on symbology in the ANVIS-HMD group would have been revealed in either failures to detect or longer reaction times for such events. For technical reasons, this type of unexpected event could not be programmed in STRATA; a limitation that has since been corrected. However, the fixation data strongly suggest that cognitive capture was not occurring in the four pilots whose eye tracking was examined in detail.

The eye tracking data revealed that pilots fixated on the symbology elements only 17.9% of the time. For three of the four pilots scored for eye tracking, maximum fixation times were 0.61, 1.02, and 1.05 sec. As Figure 5 shows, about 75 percent of the fixations were about a quarter of a second duration or less. The fourth pilot, who had 25 instances of fixations greater than 1.5 sec, could very well have been experiencing cognitive capture. However, examination of this pilot's performance data revealed he was not responsible for striking wires, or colliding with trees at the FARP and enroute, nor was he among the five poorest performing pilots in the experiment. In fact, his overall rank was 12 out of 25 on the key performance variables used to characterize the best and poorest performers. Moreover, the possibility exists that these large fixation values were the result of the eye tracker technical problems that rendered the eye tracking data of other pilots unusable. Even if his long fixations times were valid, they were not associated with substandard flying or safety performance.

Further evidence argues against the occurrence of cognitive capture. Only 5.4% of the fixation periods involved two or three HMD elements viewed in succession. This finding suggests that the pilots were sampling points across the visual scene, a strategy that did not involve prolonged fixations on single or multiple elements in the symbology suite. And the data show that they were not dwelling on the symbology suite. Although the research literature has documented that attentional focus does not necessarily coincide with the area of foveal fixation (e.g., Eriksen & Yeh, 1985), the capacity to process information when attention is decoupled from the area of foveal fixation is severly limited (Johnson & Dark, 1986). In the dynamic visual environment experienced by these pilots, it seems likely that they were directing attention to where they were looking. Therefore, the conclusion is that, among these four pilots, no evidence of cognitive capture on elements of the HMD was found.

Individual Differences

Two different types of findings are considered from the individual differences perspective. The first is the influence of eye dominance (i.e., sighting dominance) and handedness on the performance of ANVIS-HMD users (i.e., pilots receiving flight information dichoptically). The second is an analysis of flight and safety performance measures with respect to the most and least successful pilots.

The recent experiment by McAnulty et al. (1992) found that right-eye dominant pilots detected more targets than left-eye dominant pilots in a situation that presented symbology to the right eye only. McAnulty et al.'s (1992) ANVIS-HMD display configuration was very similar to the one used in this experiment, in which symbology likewise was presented to the right eye. The present experiment found no superior target detection related to eye dominance, but did reveal that right-eye dominant pilots recorded few collisions. The only significant effect of eye dominance found for the right-eye dominant ANVIS-HMD users was a higher rate of target false alarms, and a tendency for fewer collisions. With no other primary performance differences associated with eye dominance, it is not possible to provide an interpretation of these findings.

One reason that eye dominance differences were not pronounced in this experiment was the low incidence of left-eye dominant subjects. Only 4 of the 13 pilots in the ANVIS-HMD group were classified as left-eye dominant, too small a number to detect statistically significant performance differences. Although the number of left-eye dominant pilots is low, as a percentage of the group (31%) it compares favorably with the 36% of left-eye dominant pilots found by McAnulty et al. (1992) and the 35% found in the general population (Morey & Simon, 1991b; Porac & Coren, 1976). Had it been possible to conduct the experiment with each ANVIS-HMD pilot viewing the symbology presented to one eye and then the other during separate missions, eye dominance effects might have been observed. This within-subject design may have had sufficient power to detect performance differences associated with eye dominance.

Handedness has frequently been used as a marker for which hemisphere of the brain is processing specific kinds of information (Morey & Simon, 1991a). To determine if any brain lateralization effects were associated with ANVIS-HMD use, handedness data were obtained from all pilots through a questionnaire (Morey & Simon, 1991b). Analysis of the handedness data of the pilots using the ANVIS-HMD revealed no correlations of handedness with any of the variables associated with monitoring the symbology and detecting targets. The only significant correlation was between handedness and the first occurrence of the master caution indicator: the more distinctly right-handed pilots responded faster to the onset of the warning signal. The most parsimonious explanation is that the right-handed pilots had the advantage of responding to the signal with their preferred hand.

The categorization of pilots into the most and least successful aviators was an alternative to comparing experimental group mean performance as a way of assessing the impact of ANVIS-HMD use. This individual differences approach considered that the

ANVIS-HMD would reveal its benefits (or its limitations) at the extremes of skill level. This approach first rank ordered all the pilots with respect to key performance measures, such as variability in airspeed and altitude, collisions with hazards, and number of target detections. Once ranked on these criteria, the most and least successful aviators were identified and compared on a variety of characteristics, such as experimental condition (ANVIS-HMD or ANVIS-only), experience level, and primary aircraft. This analysis showed a tendency for low experience, UH-60 qualified aviators to have performed the best in this experiment. This finding is reasonable. Low experience aviators have not developed the finely tuned motor programs and automaticity of actions associated with their primary aircraft as have the more experienced aviators. Therefore, low experience aviators were more adaptable to the control characteristics of the simulated AH-64, on which no pilots in the experiment were qualified. In the case of low experience aviators who also were UH-60 qualified, they came into the experiment with experience on an aircraft that shares some of the input-control characteristics of the AH-64. They may also have benefited from experience in a UH-60 visual flight simulator.

Experience as UH-1 pilots, duty position in the unit, eye dominance, and sex of the aviator did not appear to be differentially associated with membership in the two success groups. The most significant difference found between the two groups was the number of pilots equipped with the ANVIS-HMD. Only one in five of the most successful pilots was an ANVIS-HMD user, whereas three of the five least successful aviators had used the ANVIS-HMD. These data appear to give a strong indication that the ANVIS-HMD was not a contributor to superior performance. In fact, the effect appeared to be the opposite--a higher percentage of ANVIS-HMD users appeared in the least successful group. It appears that rather than contributing to the performance of the best aviators, the ANVIS-HMD emerged as a source of difficulty for the least successful aviators.

Conclusions and Recommendations

The performance enhancements anticipated for pilots using the ANVIS-HMD did not occur in the present experiment. Maintaining airspeed and altitude, detecting targets, detecting and avoiding unmarked wire obstacles, and scanning within the field of view show no significant improvement for aviators using the ANVIS-HMD, as compared to aviators flying with only the ANVIS and traditional look-down instrumentation. The anticipated situation of cognitive capture did not arise for aviators in either the ANVIS-HMD or ANVIS-only conditions. Visual clutter, and not cognitive fixation, most likely contributed to the difficulties some ANVIS-HMD aviator subjects experienced while landing in a confined area. Such a problem could be easily solved by permitting the aviator to turn the symbology display off (an option not available in the present experiment).

Aviators equipped with the ANVIS-HMD appeared to use it effectively for monitoring essential flight information. However, remaining in the head-up mode over 85 percent of the time did not result in any improvements in visual scanning. Eye tracking data revealed only average levels of side-to-side scanning, despite the emphasized need to maintain a good scanning pattern under low altitude, night vision flight conditions. Aviators placed in the ANVIS-only condition exhibited similar problems with scanning.

The failure of this experiment to demonstrate significant performance differences with the use of the ANVIS-HMD is due in part to a confounding effect associated with aviator experience and the STRATA's flight handling characteristics. For this experiment, subjects were selected on the basis that they had no previous experience with head-up or helmet-mounted symbology displays. Specifically, aviators with prior flight experience in the AH-64 helicopter were excluded from the study because of that helicopter's Integrated Helmet and Display Sight Subsystem (IHADSS), an HMD display system. On the other hand, the handling characteristics of the STRATA simulator have been tuned to closely match those of the AH-64 helicopter. As a result, a number of the non-AH-64 aviators experienced difficulty in adjusting to the simulator's handling characteristics--despite periods of familiarization flying. These difficulties were reflected in the large analysis of variance error terms, which in many cases equalled the magnitude of the treatment effects.

We suspect, then, that insufficient HMD experience and unfamiliarity with STRATA's handling characteristics affected aviator workload and the amount of attention that could be devoted to obstacle avoidance and accomplishing mission goals. Thus, in a number of cases, performance differences due to aircraft handling problems dwarfed those differences due to experimental condition (ANVIS-HMD versus ANVIS-only).

Herein lies the issue for future research in this area. It is quite possible that problems with cognitive capture will arise for only a percentage of the aviators transitioning to the use of ANVIS-HMD equipment. These aviators may, in fact, experience such problems precisely because of their marginal aviator skills (i.e., cognitive capture might arise due to skill weaknesses and the need to focus attention on selected aspects of the flying tasks). On the other hand, aviators with superior skills may encounter little difficulty in adjusting to the use of ANVIS-HMD equipment. Translating such problems into safety concerns, the potential exists for a familiar pattern to emerge: aviation mishaps resulting from the introduction of ANVIS-HMD systems will be largely due to a relatively small percentage of the aviator population of the Army.

Identifying the factors that contribute to ANVIS-HMD induced accidents is challenging with respect to research designs and performance assessment. Nevertheless, the potential cost of such accidents (in both dollars and human lives) suggests that such research offers considerable leverage. Thus, it is important to carefully define the type of research required for meeting this challenge. In this spirit, the following points have been drawn from the present research project:

1. One focus of future research should be placed on determining the extent to which ANVIS-HMD induced cognitive capture arises as a function of aviator skill and proficiency level. The goal of this research should be to identify those skill deficiencies that make an aviator susceptible to cognitive capture with the ANVIS-HMD equipment.

2. Having identified relevant predictors of cognitive capture, the research focus should move next to the identification of training strategies that will promote good scanning habits under ANVIS-HMD conditions. A specific goal of this research should be to identify techniques for breaking attentional fixation and shifting attention back and forth from the symbolic world to the outside world.

3. Such research should consider the use of AH-64 aviators as test subjects in STRATA to avoid the confounding effects produced in the present experiment. However, experiments examining the acquisition of HMD skills or strategies in aviators unfamiliar with HMDs must rely on utility or scout pilots as test subjects. These subjects should be grouped according to the results of extensive STRATA simulator pretesting or familiarity training.

4. At present, we believe that the type of tasks used in the present experiment would be adequate for future research. However, special attention should be focused on selecting tasks that result in the largest performance differences among aviator subjects. Large performance differences improve the sensitivity for identifying the conditions associated with cognitive capture.

5. Although not specifically identified as a confound in the present experiment, future research interest should be focused on the potential biasing effect induced by the helmet-mounted virtual display used in STRATA. Specifically, further investigations should be conducted with this type of display to determine if its weight and cable tension inhibit side-to-side scanning over a period of time. Although this issue is important for any future research conducted in the STRATA device, it is critical for any research specifically addressing factors that inhibit or promote scanning.

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Appendix A

STRATA Description and Experiment Instructions

STRATA Description

Before I provide you the instructions for the experiment, let me take a few minutes and describe this facility to you. This simulator is called the Simulation Training Research Advanced Testbed for Aviation, or STRATA for short. The Army Research Institute owns the STRATA, and recently installed it for a variety of research and development purposes. Because it is designed as a research facility, the STRATA is probably unlike other simulators you have used.

To give you an idea of how the STRATA is different, I will first tell you about some of the research purposes for which it will be used. Then I will describe some of its physical features.

One of the uses of the STRATA is to conduct training research. Trainers frequently need to know the training requirements for new systems, or for modifications to existing systems. During the development of a new or modified system, a prototype can be configured on the STRATA. Tasks that need to be trained, the amount of training these tasks require, different approaches to training, and training standards can all be investigated with the prototype while the actual system is still under development. This kind of research supports the goal of having training programs ready when new systems are fielded.

In much the same way that training can be explored for new systems, new subsystems such as navigation, imaging, or weapons systems can be prototyped on the STRATA. Mock-ups of the hardware components, and software simulations of the new system's operation, can be installed on the STRATA. The operational impacts of the new system can be observed as pilots use it under a variety of tactical and environmental conditions. The use of the STRATA as a testbed for prototypes of new subsystems, or even entirely new aircraft, is part of a trend to use simulators during system design and evaluation.

A third use of the STRATA is to evaluate new aviation tactical doctrine. A part of the STRATA's capability is artificial intelligence software that can incorporate doctrinal principles and procedures in the form of knowledge-based rules. Up to 180 different players can be defined for a tactical scenario in the STRATA. These players can be either ground-based stationary systems such as radar sites, or vehicles such as tanks or trucks. Aerial players such as helicopters and fixed wing aircraft can also be defined. The physical capabilities and doctrinal actions of each of these players can be individually specified to make up a tactical scenario. A pilot like yourself flying his own ship in the scenario can interact with these defined players, each of which is following its doctrine. Players and doctrine can be defined for friendly and enemy forces. Performance can be measured for the pilot's ship and for the other players as well. In this way new doctrinal ideas can be evaluated.

A fourth purpose of the STRATA is to investigate designs and uses of simulations. The STRATA is a simulator that can be used to design and evaluate new approaches to simulation. Examples of research of this kind are investigations into how much detail needs to be provided in the visual imagery, or whether some functions can be trained on less complex simulators.

Now that you have an idea of the different uses of the STRATA, let me describe some of its most important features. First of all, the STRATA uses Apache pilot and copilot stations. The cockpits are entirely made up of actual components. In terms of operational characteristics, the aerodynamics of the Apache have been modeled in the STRATA's software. The result is that from the pilot's perspective the STRATA looks and feels like an Apache. By design, however, this can be modified as needed by exchanging other cockpits and adding other aircraft aerodynamic models.

Another feature of the STRATA is that it is not a full motion simulator. The sensation of movement is provided by movements of the visual scene, and also by a system of inflatable bladders in the seat and seat back. The lap belts also pull against the pilot's body. This seat configuration is called the G-seat. As the aircraft maneuvers, the bladders inflate and deflate to simulate the pressure of your body against the seat. The lap belts likewise tighten and loosen. This simulation has proven to be quite effective in inducing some of the sensations of movement.

Yet another feature of the STRATA--which is perhaps its most revolutionary--is the manner in which the visual image is projected. The reason that you had to have a helmet fitted was to provide a very steady supporting structure for visual imaging systems that provide images to each of your eyes. I will use this diagram to help explain the system to you. [Show helmet illustration]. The image generator computers provide visual signals to devices called light valves. The light valves intensify the visual signals so they can be transmitted by fiber optic cables up to the helmet. The visual images are projected onto small pancake windows in front of each eye. The pancake windows act like miniature CRTs.

Each eye receives two kinds of images. One of the images is a lower resolution background image that covers most of what that eye sees. A small portion in the center of the field of view is called the inset. The inset is generated at a higher level of resolution that coincides with the eye's area of greatest acuity, called the foveal area. This arrangement of higher and lower resolution is less demanding of computer resources, and takes advantage of the central and peripheral acuity characteristics of the eye.

During your cockpit orientation, the engineers will adjust the two eye pieces so that the left and right eye images blend both for the background and for the insets.

With this helmet-mounted system, as you move your head from side to side and up and down, you will see the terrain, objects, and parts of the aircraft that should appear at those locations in your field of view. The computer knows where you are looking, because it uses a head tracker to keep track of the orientation of your head in space. Theoretically, you have the capacity to see things 360° around you, but as a practical matter your head movements are restricted to about 90° to the left and right.

Notice on the illustration that eye trackers are positioned above each eye piece. These devices provide information on where the center of your pupil is pointing. In other words, the eye tracker provides data on where you are looking within your field of view. We will be using the eye tracker during the experiment. This will require that we go through a short calibration procedure.

Another feature of the STRATA is that it provides for both pilot and copilot-gunner stations, just as they are in the actual Apache. We will not be using the copilot's station today. We will provide a navigator through one of the control stations. Questions?

Instructions of ANVIS-HMD Subjects

ANVIS-HMD Condition

Note: Before beginning, determine if subject is in the HUD or non-HUD condition.

Verify that pilot has had helmet poured and has completed initial optical alignment.

Verify that the pilot knows the experiment is a full day commitment until about 1530 today.

1. Show pilot to briefing area and introduce yourself.

2. Describe what will be covered in the briefing: STRATA, overview of experimental procedures, schedule for the day, and questionnaires.

As you may know, the Army is planning to integrate a head-up display of instrument symbology (HUD) into the Aviation Night Vision Imagery System (ANVIS). The ANVIS-HMD will be introduced into the fleet of helicopters over the next few years. Of particular interest to Army aviators is the attentional and cognitive demands of using the ANVIS-HMD under demanding conditions such as flying NOE. This combination is regarded by most aviators as very demanding of attention. Data from this experiment will show the operational effects of the ANVIS-HMD combination, and provide early indications of the training requirements for transitioning pilots to the ANVIS-HMD. I will tell you how we are going to create the night vision and HUD conditions in a few minutes.

During the main part of the experiment you will be tasked with flying a reconnaissance mission. The mission will take about one hour and will involve flying over enemy occupied areas. However, you will not come under fire or be required to use your weapon systems. Your primary task will be to search for enemy ground targets. Exactly what you need to do when you encounter targets will be explained in a few moments. You will be flying your mission at altitudes in the 100 ft AGL range. You will need to be especially watchful for low level obstacles and wires.

Because you will not be flying with a copilot in the other seat of the simulator, we will provide a navigator who will give you navigation instructions from one of the control stations. You will not need to use standard radio procedures. Communications will be handled using a hot microphone intercom between you and the navigator. You can talk back and forth with the navigator without having to press any switches.

Part of the mission will require you to report sightings of targets. You will need to signal that you've detected targets by pulling a weapon system trigger. We will show you which trigger during your cockpit orientation. Once you've identified the targets, you will give a verbal report of what kinds of targets you saw. Your verbal report should be in spot report format like this: "Three BMPs at 2 o'clock, 200 meters." The navigator will make note of the location of the targets. If you cannot exactly name the ground target, it is okay to report "Three tracked vehicles, 2 o'clock, 200 meters."

Let me recap the target reporting procedure. Once you detect a ground target or targets, you first respond with a trigger pull. Then follow up with a spot report. You will tell the navigator what kind and how many ground targets you saw, give their clock position relative to you, and report the range to the targets.

Do you have any questions up to this point?

As I mentioned earlier, the purpose of this experiment is to see the effects of combining HUD symbology with night vision goggles. Because the SCTB presents images to the pilot's eyes through eye pieces on the helmet, we do not use actual night vision goggles. Instead, we have configured the image generator to present a 40° circular field of view to your eyes. In addition, we have tuned the image to simulate the color and resolution of the ANVIS. As a result, the visual effect is similar to night vision goggles. As with the real ANVIS, you will have to scan from side to side as you fly the mission. Unlike other simulators you may have flown, you have a complete view from side to side as you turn your head.

I need to mention that some of the optic fibers used to transmit the image to the helmet eye pieces have become damaged. As a result you will see a few vertical black lines that are not part of the visual imagery. During the cockpit familiarization, we will make sure these lines are not blocking important parts of the visual scene.

An important feature of this experiment is the effect of using the HUD while flying with NVGs. The HUD that we will be using has 11 flight parameters. Let me show you a diagram of the HUD symbology and explain its features to you.

[Give pilot a diagram of the HUD as he will see it and the labelled diagram. Describe each of the elements.]

The HUD takes up an area in the center of the field of view. The symbology is presented to the right eye only, but both eyes view the scene outside the cockpit. The cockpit instrument console is not part of the visual simulation. You can directly view the instrument panel by looking down.

However, you will be required to monitor the instruments in the HUD that I described to you earlier. You will not be able to obtain readings from the corresponding instruments on the cockpit console. The navigator will provide specific altitude and airspeed values to you. You will be required to maintain these values during various legs of the mission. He will also provide headings and course directions.

Make a note that the master caution indicator may come on during the mission. We will not ask you to deal with a specific malfunction or emergency on the helicopter. However, you will have to reset the indicator. You will use the same weapons system trigger that is used for target detections. When you see the master caution indicator come on, pull the trigger and tell the navigator "Master Caution." The trigger pull will reset the indicator. We will show you how to do that during your cockpit orientation. You will get a chance to practice this during your familiarization flight.

Once we finish with this briefing, you will receive a cockpit orientation, have your helmet optically tuned, and then take a familiarization flight. The first part of the flight will be under daylight conditions to let you get a feel of the aircraft. We will then convert to the ANVIS-HMD condition and let you fly for about half an hour. You will need to monitor the HUD and search for targets exactly as you will during the actual mission. The area you will be flying is similar to, but not the same as, the area flown in the actual mission. After you are comfortable flying the simulator, we will break for lunch. After lunch, you will receive a mission briefing and return to the simulator for the reconnaissance mission. We will then finish up with a short debriefing.

Do you have any questions at this point?

Now that I have explained the SCTB and the experiment, I need to ask if you are willing to serve as a participant in this experiment. [Solicit if pilot is willing.] Okay, since you have agreed to participate, in a moment I will give you an informed consent form to read and sign. We will then ask you to take a few minutes to complete a short biographical questionnaire. Next, we will ask you to complete a questionnaire about your preferences for which hand you use to perform common tasks. We will finish up by doing a short test of eye preference.

[Administer questionnaires]

Before we get started, a couple of administrative details. The restrooms are located over here [point out location]. Also, we have complimentary soft drinks and snacks located behind the cockpit [point out location]. We also have coffee in the office. Anytime during the day that you are on break, help yourself to whatever you wish. They are on the house!

ANVIS-Only Condition

Note: Before beginning, determine if subject is in the HUD or non-HUD condition.

Verify that pilot has had helmet poured and has completed initial optical alignment.

Verify that the pilot knows the experiment is a full day commitment until about 1530 today.

1. Show pilot to briefing area and introduce yourself.

2. Describe what will be covered in the briefing: SCTB, overview of experimental procedures, schedule for the day, and questionnaires

As you may know, the Army is planning to integrate a head-up display of instrument symbology (HUD) into the Aviation Night Vision Imagery System (ANVIS). The ANVIS-HMD will be introduced into the fleet of helicopters over the next few years. Of continuing interest to Army aviators is the attentional and cognitive demands of using the ANVIS just by itself. A more recent issue is the additional cognitive demands the ANVIS-HMD will impose, especially under demanding conditions such as flying NOE. Because we are investigating a variety of operational issues concerning flying with night vision systems, today you will be flying just with the ANVIS. Other participants in this research will be flying with the ANVIS-HMD combination. However, results from everyone will be used to provide early indications of the training requirements for both the current ANVIS and the new ANVIS-HMD system. I will tell you how we are going to create the night vision conditions in a few minutes.

During the main part of the experiment, you will be given the task of flying a reconnaissance mission. The mission will take about one hour and will involve flying over enemy occupied areas. However, you will not come under fire or be required to use your weapon systems. Your primary task will be to search for enemy ground targets. Exactly what you need to do when you encounter targets will be explained in a few moments. You will be flying your mission at altitudes in the 100 ft AGL range. You will need to be especially watchful for low level obstacles and wires.

Because you will not be flying with a copilot in the other seat of the simulator, we will provide a navigator who will give you navigation instructions from one of the control stations. You will not need to use standard radio procedures. Communications will be handled using a hot microphone intercom between you and the navigator. You can talk back and forth with the navigator without having to press any switches.

Part of the mission will require you to report sightings of targets. You will need to signal that you have detected targets by pulling a weapon system trigger. We will show you which trigger during your cockpit orientation. Once you have identified the targets, you will give a verbal report of what kinds of targets you saw. Your verbal report should be in spot report format like this: "Three BMPs at 2 o'clock, 200 meters." The navigator will make note of the location of the targets. If you cannot exactly name the ground target, it is okay to report "Three tracked vehicles, 2 o'clock, 200 meters."

Let me recap the target reporting procedure. Once you detect a ground target or targets, you first respond with a trigger pull. Then follow up with a spot report. You will tell the navigator what kind and how many ground targets you saw, give their clock position relative to you, and report the range to the targets.

Do you have any questions up to this point?

As I mentioned earlier, the purpose of this experiment is to obtain data about attention when flying with night vision goggles. Because the SCTB presents images to the pilot's eyes through eye pieces on the helmet, we do not use actual night vision goggles. Instead, we have configured the image generator to present a 40° circular field of view to your eyes. In addition, we have tuned the image to simulate the color and resolution of the ANVIS. As a result, the visual effect is similar to night vision goggles. As with the real ANVIS, you will have to scan from side to side as you fly the mission. Unlike other simulators you may have flown, you have a complete view from side to side as you turn your head.

I need to mention that some of the optic fibers used to transmit the image to the helmet eye pieces have become damaged. As a result, you will see a few vertical black lines that are not part of the visual imagery. During the cockpit familiarization we will make sure these lines are not blocking important parts of the visual scene.

Make a note that the master caution indicator may come on during the mission. We will not ask you to deal with a specific malfunction or emergency on the helicopter. However, you will have to reset the indicator. You will use the same weapon system trigger that is used for target detections. When you see the master caution indicator come on, pull the trigger and tell the navigator "Master Caution." The trigger pull will reset the indicator. We will show you which trigger to use during your cockpit orientation. You will get a chance to practice this during your familiarization flight.

Once we finish with this briefing, you will receive a cockpit orientation, have your helmet optically tuned, and then take a familiarization flight. The first part of the flight will be under daylight conditions to let you get a feel of the aircraft. We will then convert to the ANVIS condition and let you fly for about half an hour. You will need to search for targets exactly as you will during the actual mission. The area you will be flying is similar to, but not the same as, the area flown in the actual mission. After you are comfortable flying the simulator, we will break for lunch. After lunch, you will receive a mission briefing, and return to the simulator for the reconnaissance mission. We will then finish up with a short debriefing.

Do you have any questions at this point?

Now that I have explained the SCTB and the experiment, I need to ask if you are willing to serve as a participant in this experiment. [Solicit if pilot is willing.] Okay, since you have agreed to participate, in a moment I will give you an informed consent form to read and sign. I will then ask you to take a few minutes to complete a short biographical questionnaire. Next, we will ask you to complete a questionnaire about your preferences for which hand you use to perform common tasks. We will finish up by doing a short test of eye preference.

[Administer questionnaires]

Before we get started, a couple of administrative details. The restrooms are located over here [point out location]. Also, we have complimentary soft drinks and snacks located behind the cockpit [point out location]. We also have coffee in the office. Anytime during the day that you ARE on break, help yourself to whatever you wish. They are on the house!

Appendix B

Biographical Questionnaire and
Data Form for Handedness and Eye Dominance

ANVIS-HMD Experiment Pilot Questionnaire

I. Background Information

(Please complete the following information regarding your personal experiences and current status)

1. Subject No. ____________ 2. Last Four SSAN ________ 3. Date________________ (day/mo/yr)

4. Current Rank ____________________ 5. Years as Rated Aviator __________

6. a. Age ______ b. Sex ______

7. Current Unit (Co/Bn/Rgt) ________________ 8. Time in Current Unit (months)________

9. Current Aviator Readiness Level (RL) 1 2 3 4 *(circle one number)*

10. Current Flight Activity Category (FAC) 1 2 *(circle one number)*

11. Current primary duty assignment in unit *(check one)*

    IP___ SP___ UT___ IFE___ MTP___ Aviator___ Other__________

12. a. Primary Aircraft ________ *(Fill in aircraft designations)*

    b. Other Rotary Wing ________

    c. Fixed Wing _________

13. Aviation Experience (Flight Hours):

	Lifetime Flying Experience		Experience over last 6 months	
	All Conditions	NVG	All Conditions	NVG
a. Primary aircraft hrs.	_________	__________	_________	______
b. Rotary Wing hrs.	_________	__________	_________	______
c. Fixed Wing hrs.	_________	__________	_________	______

14. a. Do you have experience with helmet-mounted symbology? Yes No *(circle one)*

    b. If yes, describe:____

    ____

    c. Did you participate in a recent experiment that used a desk-top device to test head-up display (HUD) instrument symbology under NVG condtions? Yes No *(circle one)*

15. Do you wear glasses or contact lenses while flying? Yes No *(circle one)*

Army Research Institute Handedness Inventory

Name: ______________________ **Social Security #:** ______________________

Sex: Male Female

Directions: Following is a listing of 12 common activities. For each activity, please indicate your preference for right or left hand by circling the appropriate response according to the following scale. Try to answer all the questions, and only use a "6 - Don't Know" if you have no experience at all with the object or task.

1 = Always use left hand
2 = Usually use left hand
3 = Use both equally
4 = Usually use right hand
5 = Always use right hand
6 = Don't Know

With which hand do you:	Always Left	Usually Left	Both Equally	Usually Right	Always Right	Don't Know
1. Write	1	2	3	4	5	6
2. Hold a nail to hammer	1	2	3	4	5	6
3. Draw	1	2	3	4	5	6
4. Use scissors	1	2	3	4	5	6
5. Use a toothbrush	1	2	3	4	5	6
6. Use a knife to carve a turkey	1	2	3	4	5	6
7. Hold a bottle to uncap (bottle hand)	1	2	3	4	5	6
8. Hold a match when striking it	1	2	3	4	5	6
9. Use a screwdriver	1	2	3	4	5	6
10. Pour a large volume of liquid from a pitcher	1	2	3	4	5	6
11. Throw a ball	1	2	3	4	5	6
12. Use a spoon	1	2	3	4	5	6

Do not write in this box		Date:
EP1 LT RT	TTL	ADMN
EP2 LT RT	Site	CTRL

Appendix C

STRATA Checksheets

ANVIS-HMD Experiment

EOS Checklist and Control Log

ANVIS-HMD Condition

Experimenter__________________ Subject____________________Date__________

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.0	FAMILIARIZATION			
1.1	Flight Controls - ON	CAE		
1.1.1	Force Trim - ON	CAE		
1.1.2	Instruments covered - Master Caution	CAE		
1.1.3	Instruments Uncovered - Analog HUD Duplicates	CAE		
1.2	G-Seat - ON	CAE		
1.3	Cockpit Power- ON	CAE		
1.4	LOGIN to EOS	Experimenter		
1.5	Engine Fast Start	Experimenter		
1.6	External Power - OFF Pneumatics - OFF	CAE		
1.7	HARS Fast Align	Experimenter		
1.8	Sound @ 50%	Experimenter		
1.9	DASE - ON	Experimenter		
1.10	VDU - OFF	CAE		
1.11	HUD - OFF	Experimenter		
1.12.1	Checkout FOHMD - Daylight Mode	CAE		
1.12.2	Checkout FOHMD - No Symbology	CAE		
1.12.3	Checkout FOHMD - LV Personalities	CAE		
1.12.4	Checkout FOHMD - Converg./Diverg.	CAE		
1.13	EOS - Setup Comms	Experimenter		
1.14	Checkout Commo	Experimenter		
1.15	Load Scenario #72	Experimenter		
1.16	Fuel Freeze - ON	Experimenter		

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.17	Sound Mute - ON	Experimenter		
1.18	EOS - TSD Setup	Experimenter		
1.19	Freeze Player #1 Position	Experimenter		
1.20	Sound Mute - OFF	Experimenter		
1.21	Begin Daylight Familiarization (Leave Scenario Frozen)	Experimenter		
1.22	End Daylight Familiarization	Experimenter		
1.23	Checkout FOHMD - **NVG** Mode: Left Inset - Stand-by	CAE		
1.24	Checkout FOHMD - Symbology Offset	CAE		
1.25	Checkout FOHMD - LV Personalities	CAE		
1.26	Instruments Covered - Master Caution	CAE		
1.27	Instruments Covered - Analog HUD Duplicates	CAE		
1.28	HUD - ON	CAE		
1.29	IHADSS - ON	CAE		
1.30	Set-up VT320 for MST	CAE		
1.31	UNFREEZE SCENARIO	Experimenter		
1.32	FREEZE SCENARIO	Experimenter		
1.33	Sound Mute - ON	Experimenter		
1.34	Put Light Valves on Standby	CAE Experimenter		
End				

ANVIS-HMD Experiment

EOS Checklist and Control Log

ANVIS-HMD Condition

Experimenter______________________ Subject________________________ Date____________

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.0	RECONNAISSANCE MISSION			
1.1	Flight Controls - ON	CAE		
1.1.1	Force Trim - ON	CAE		
1.1.2	Instruments Covered - HUD Analog Duplicates	CAE		
1.1.3	Instruments Covered - Master Caution	CAE		
1.2	G-Seat - ON	CAE		
1.3	Cockpit Power- ON	CAE		
1.4	Engine Fast Start	Experimenter		
1.5	External Power - OFF Pneumatics - OFF	CAE		
1.6	HARS Fast Align	Experimenter		
1.7	Sound @ 50%	Experimenter		
1.8	DASE - ON	Experimenter		
1.9	VDU - OFF	CAE		
1.10	HUD - ON	Experimenter		
1.11	IHADSS - ON	CAE		
1.12.1	Checkout FOHMD- NVG Mode: Left Inset - Stand-by	CAE		
1.12.2	Checkout FOHMD - Symbology Offset	CAE		
1.12.3	Checkout FOHMD LV personalities	CAE		
1.13	Checkout Commo	Experimenter		
1.14	Load Scenario #69	Experimenter		
1.15	Fuel Freeze - ON	Experimenter		
1.16	Sound Mute - OFF	Experimenter		
1.17	Initialize DRA	Data Specialist		

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.18	EOS - TSD Setup	Experimenter		
1.19	Freeze Player #1 Position	Experimenter		
1.20	Set up VT 320 for MST	Experimenter		
1.21	Set UTM and Heading for HUD Registration: RUPOSX 297923.8 RUPOSY 416919.8 Heading 250°	CAE		
1.22	Set Up Video Tape	Experimenter		
1.23	Sound Mute - OFF	Experimenter		
1.24	START SCENARIO	Experimenter		
1.25	FREEZE Scenario	Experimenter		
1.26	Close DRA	Data Specialist		
1.27	Unload Video Tape	Experimenter		
1.28	Put Light Valves on Stand-by	CAE		
End				

ANVIS-HMD Experiment

EOS Checklist and Control Log

ANVIS-Only Condition

Experimenter______________________ Subject________________________ Date____________

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.0	FAMILIARIZATION			
1.1	Flight Controls - ON	CAE		
1.1.1	Force Trim - ON	CAE		
1.1.2	Instruments Uncovered - Master Caution HUD Analog Duplicates	CAE		
1.2	G-Seat - ON	CAE		
1.3	Cockpit Power- ON	CAE		
1.4	LOGIN to EOS	Experimenter		
1.5	Engine Fast Start	Experimenter		
1.6	External Power - OFF Pneumatics - OFF	CAE		
1.7	HARS Fast Align	Experimenter		
1.8	Sound @ 50%	Experimenter		
1.9	DASE - ON	Experimenter		
1.10	VDU - OFF	CAE		
1.11	HUD - OFF	Experimenter		
1.12	IHADSS Switch - OFF	CAE		
1.13.1	Checkout FOHMD - **Daylight** Mode	CAE		
1.13.2	Checkout FOHMD - No Symbology	CAE		
1.13.3	Checkout FOHMD - LV Personalities	CAE		
1.13.4	Checkout FOHMD - Converg./Diverg.	CAE		
1.14	EOS - Setup Comms	Experimenter		
1.15	Checkout Commo	Experimenter		
1.16	Load Scenario #72	Experimenter		
1.17	Fuel Freeze - ON	Experimenter		

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.18	EOS - TSD Setup	Experimenter		
1.19	Freeze Player #1 Position	Experimenter		
1.20	START SCENARIO	Experimenter		
1.21	FREEZE SCENARIO	Experimenter		
1.22	Checkout FOHMD NVG Mode: Left Inset - OFF Right Inset - OFF	CAE		
1.23	Checkout FOHMD - No Symbology	CAE		
1.24	Checkout FOHMD - LV Personalities	CAE		
1.25	Set up VT320 for MST	CAE		
1.26	UNFREEZE SCENARIO	Experimenter		
1.27	FREEZE SCENARIO	Experimenter		
1.28	Sound Mute - ON	Experimenter		
1.29	Put Light Valves on Standby	CAE Experimenter		
End				

ANVIS-HMD Experiment

EOS Checklist and Control Log

ANVIS-Only Condition

Experimenter________________________ Subject________________________ Date____________

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.0	RECONNAISSANCE MISSION			
1.1	Flight Controls - ON	CAE		
1.1.1	Force Trim - ON	CAE		
1.1.2	Instruments Uncovered	CAE		
1.2	G-Seat - ON	CAE		
1.3	Cockpit Power- ON	CAE		
1.4	Engine Fast Start	Experimenter		
1.5	External Power - OFF Pneumatics - OFF	CAE		
1.6	HARS Fast Align	Experimenter		
1.7	Sound @ 50%	Experimenter		
1.8	DASE - ON	Experimenter		
1.9	VDU - OFF	CAE		
1.10	HUD - OFF	Experimenter		
1.11	IHADSS Switch - OFF	CAE		
1.12.1	Checkout FOHMD- **NVG** Mode: Left Inset - OFF Right Inset - OFF	CAE		
1.12.2	Checkout FOHMD - No Symbology	CAE		
1.12.3	Checkout FOHMD LV personalities	CAE		
1.13	Checkout Commo	Experimenter		
1.14	Load Scenario #69	Experimenter		
1.15	Fuel Freeze - ON	Experimenter		
1.16	Initialize DRA	Data Specialist		
1.17	Set up VT320 for MST	CAE		
1.18	EOS - TSD Setup	Experimenter		

Sequence Number	Action/ Procedure	Responsibility	OK	Notes
1.19	Sound Mute - OFF	Experimenter		
1.20	Freeze Player #1 Position	Experimenter		
1.21	Load Video Tape	Experimenter		
1.22	START SCENARIO	Experimenter		
1.23	FREEZE SCENARIO	Experimenter		
1.24	Close DRA	Data Specialist		
1.25	Unload Video Tape	Experimenter		
1.26	Put Light Valves on Stand-by	CAE Experimenter		
End				

Appendix D

Experimenter/Navigator Log Sheet

ANVIS-HMD Experiment
Experimenter/Operator Station Data Sheet

Subject Number_____ Date______________ Condition: NVG Only
ANVIS/HUD

Subject Name__________________________ Last Four_________________

I. Familiarization (Record duration for major morning activities)

Cockpit Orientation _____

Adjustments (Optical, Hardware, Software) _____

Daylight Practice Ride (Total Time Controlling Aircraft) ______

NVG Practice Ride (Total Time Flying) _____

Other (Specify)

II. Reconnaissance Target Detections and Indentifications

Target No.	Number of Targets Reported	Type of Target Reported	Comments
1			
2			
3			
4			
5			
6			
7			
8			
9			

Target False Alarms

Use this space to make tic marks	Total

Record of Speed or Altitude Warnings Made by Navigator (after start point)

Use this space to make tic marks	Total

Appendix E

Debriefing Forms

ANVIS-HMD Experiment
Debriefing Data Sheet

ANVIS-HMD Condition

Subject Number_____ Date______________

Subject Name________________________________ SSAN________________

1. What is your opinion of the realism of the NVG image? ________

2. Describe any problems you may have had flying with the NVG ____

3. Did you have any problems viewing the HUD symbology? (fixation on symbology, lapses of attention, binocular rivalry, quality of image) ________________

4. Do you have any opinions on the kinds of instruments displayed in the symbology and their locations in the display? ____________

5. Can you describe how you monitored the HUD symbology.
Scanning strategy________________

Dividing attention between OTW and HUD ____________________

6. Was the mission sufficiently challenging? Were some segments more challenging than others? ____________________

7. Describe any problems you may have had with physical discomfort.

Visual ____________________

Helmet ____________________

G-Seat ____________________

Cockpit Cooling ____________________

Other ____________________

8. Do you think you had sufficient practice during the morning familiarization flight? YES NO Comments ____________________

9. Did you experience any motion sickness? YES NO Comments______

10. Other Comments

CAUTION SUBJECT NOT TO DISCUSS THE EXPERIMENT WITH OTHERS

ANVIS-HMD Experiment
Debriefing Data Sheet

ANVIS-Only Condition

Subject Number_____ Date______________

Subject Name________________________________ SSAN________________

1. What is your opinion of the realism of the NVG image? ________

2. Describe any problems you may have had flying with the NVG ____

3. Was the mission sufficiently challenging? Were some segments more challenging than others? ____________________

4. Describe any problems you may have had with physical discomfort.

Visual ____________________

Helmet ____________________

G-Seat ____________________

Cockpit Cooling ____________________

Other ____________________

5. Do you think you had sufficient practice during the morning familiarization flight? YES NO Comments ____________________

____

____

____

__

6. Did you experience any motion sickness? YES NO Comment______

____

____

____

____

6. Other comments

CAUTION SUBJECT NOT TO DISCUSS THE EXPERIMENT WITH OTHERS

Appendix F

Range-to-Target Detection Distance Data

Table F-1

Descriptive Statistics and Analysis of Variance Results on Range-to-Target Detection Distance Data (in meters)

Target site no.	No. of pilots that detected	ANVIS-only Low experience	ANVIS-only High experience	ANVIS-HMD Low experience	ANVIS-HMD High experience	Analysis of variance factors: Experimental condition	Experience level	Interaction
TS1	17	M = 709.0 SD = 333.2 n = 4	M = 742.1 SD = 352.3 n = 5	M = 581.5 SD = 182.0 n = 4	M = 688.8 SD = 216.7 n = 4	$F < 1$	$F < 1$	$F < 1$
TS2	1							
TS3	10	M = 400.0 SD = 141.1 n = 3	M = 434.8 SD = 53.5 n = 2	M = 251.0 SD = 215.7 n = 4	M = 265.5 SD = 0.0 n = 1	NC	NC	NC
TS4	16	M = 658.9 SD = 348.3 n = 5	M = 906.2 SD = 301.4 n = 4	M = 712.6 SD = 297.5 n = 6	M = 710.7 SD = 0.0 n = 1	$F < 1$	$F < 1$	$F < 1$
TS5	18	M = 514.7 SD = 308.2 n = 5	M = 586.7 SD = 431.7 n = 5	M = 654.8 SD = 238.0 n = 6	M = 734.9 SD = 164.2 n = 2	$F < 1$	$F < 1$	$F < 1$
TS6	11	M = 408.5 SD = 80.9 n = 5	M = 478.7 SD = 129.4 n = 2	M = 435.2 SD =101.9 n = 3	M = 972.7 SD = 0.0 n = 1	NC	NC	NC
TS7	15	M = 640.7 SD = 217.7 n = 3	M = 795.5 SD = 60.7 n = 4	M = 576.8 SD = 84.0 n = 4	M = 469.5 SD = 155.7 n = 4	F (1,14) = 8.60 p = .014	$F < 1$	$F < 1$
TS8	13	M = 202.3 SD = 176.8 n = 4	M = 199.0 SD = 64.7 n = 5	M = 204.0 SD = 24.9 n = 2	M = 246.6 SD = 77.3 n = 2	$F < 1$	$F < 1$	$F < 1$
TS9	18	M = 889.6 SD = 73.2 n = 4	M = 814.6 SD = 282.6 n = 5	M = 762.3 SD = 218.2 n = 6	M = 361.9 SD = 4.08 n = 3	F (1,17) = 7.61 p = .015	F (1,17) = 5.41 p = .036	F (1,17) = 2.72 p = .121

Note. NC = not computed.